Study on Determinant Factors of Economic Feasibility in generating Wind Power in Northeast Brazil

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Editora Poisson

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RESEARCH PROJECT

Study on Determinant Factors of Economic Feasibility in generating Wind Power in Northeast Brazil

Research conducted in partnership with the universities of Porto and Minho and the Brazilian Federal University of Ceara, finished in July 2019, in the city of Porto, Portugal

"Brazil has been very proactive in renewable sources, both wind and solar, and has an ambitious program to increase this share of wind energy in the country's energy matrix" Fabio Lopes - Secretary of Brazilian Energy of the Ministry of Mines and Energy

PREFACE

The Energy policy has been trying, throughout these last 50 years, to manage three dimensions which, in the short-term, are of difficult compatibility between them: (i) security in the supply, (ii) energy/environment interface and (iii) efficiency and competiveness.

The difficulties in implementing a consistent and comprehensive energy policy are not, nonetheless, a recent challenge. It happens that the generic instruments for energy policy – with the exception of the one promoting efficiency and sufficiency – by contributing individually to each of these dimensions, may further separate them, particularly if designed in timeframes more appealing to legislative cycles rather than societal, economical or natural cycles.

Everything was clearer when it became possible to privilege each of these dimensions:

- In the 70's, after the oil shock, the concern with security in supply was the priority;
- In the 80's, after the appearance of oil slicks at open sea;
- acid rains and nuclear incidents, which made it easy to elect environment as the energy policy driver;
- In the 90's, when energy pricing was subjected to a higher stress, the model of public and vertical monopolies was severely shaken throughout the western world.

The situation today is challenging: there is a world explosion in the use of energy nowadays, placing pressure on the supply and forcing the formulation of new geostrategic approaches; the anthropogenic action on climate is also unquestionable and is leading to a very energy focused climate action; globalization is placing energy prices as a driver of competitiveness. And all of this at the same time!

The current energy transition is challenging but further complexity must be added: energy policies require local adjustment as, despite the universal principles, many solutions not present the same composition or even are the same in every site, in every country or in every region of the world. It is, therefore, true that the situation was never so complex for policy makers and sector professionals given the so many existing drivers and externalities.

Although the difficulty to dose the medication cocktail to such complex framework, it is necessary to start somewhere and the present study is a good starting point focusing in the competitiveness aspect of wind power, specific to northeast Brazil.

Prof. Araujo invites us, with this book, to travel along with him through his research project on the determinant factors of the economic feasibility of wind power in northeast Brazil.

One may question the pertinence of such matter at a time when Brazilian market mechanisms (auctions, free market actions, etc.) are relatively mature. But not only the prospect of new market mechanism is, as always, on top of the table but the acknowledgement of renewables sources-based electricity as a vector (rather than a final form) is increasing at a fast pace: technological ruptures based, for example, in Power-to-X facilities sourced in “green” electricity will further add pressure on the supply side, forcing the sector to invest in this area.

But if the demand side is expected to grow, albeit the pressing needs for energy efficiency and sufficiency, the supply side will require rationality: nowadays, renewables are not a particularity but a mainstream sector instead and support mechanisms are lowering.

It is with this scope that, in a very transparent way, Prof. Araujo Junior not details the main components of the CapEx and OpEx and all the engineering and financial variables taken into account during the development, installation and operation of a wind farm, but also provides what is the business plan as a decision-making tool.

By doing so, and by setting a benchmark with a different and mature market such as the Portuguese one, Prof. Araujo Junior also sets the tone for the return any investor should expect by moving forward with wind power in northeast Brazil.

Prof. Dr. José Carlos Coelho Fernandes de Matos
INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial

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CHAPTER

01 INTRODUCTION

This research is linked to a sabbatical proficiency program in the State University of Rio de Janeiro (UERJ), aimed at conducting post-doctoral studies and research to enable its researchers to improve and update their scientific and academic knowledge through the development of projects with innovative technological content, stimulating cooperation between Higher Education Institutions in Brazil and international universities abroad.

Wind energy is an additional source of renewable energy, that is, those energies that do not harm the environment and fits in the group of alternative energies.

Nowadays, the idea that wind energy is an expensive source, is still very common. On the contrary, this kind of energy is not only an economically competitive and accessible energy source but also a clean source. It should be mentioned in this context that costs of implementing wind energy projects have decreased substantially over the past 10 years.

1.1 Perspective of wind power generation in Brazil

Brazil has one of the cleanest energy matrices in the world, mainly a matrix based on hydro power. The country can be considered the most promising market for wind energy in Latin America, with an estimated wind potential of 300 GW (some analysts consider even a potential of 500 GW) and the energy demand is expected to increase by 2 GW per year until 2020. Moreover, wind conditions in Brazil are characterized as strong and stable.

The focus on the Brazilian wind energy sector is mainly onshore, due to lower cost and land availability and sector specialists do not foresee a promising future for offshore wind energy in Brazil within the next 10 to 20 years.

One decade ago, more than 80% of the electricity generation installed capacity was linked to sustainable sources due mainly to 158 operating hydraulic plants operating in Brazil; Brazil's fundamental energy model has long been based around hydroelectric power and even today, 70% of Brazil's renewable electricity still comes from large hydraulic sources, like the Itaipu hydroelectric dam, the second largest in this type in the world.

The development of new hydro plants can no longer be maintained due to geographical circumstances, strong climate change in the last decade and strict environmental regulations, which led the Brazilian government to shift its focus towards renewable energy sources. In this way, Brazil tries to diversify electricity production away from hydropower.

In this sense, specialists point to a growth of the wind energy participation in Brazil's energy matrix. This segment which is already responsible for 8.3% of the energy produced in the country, a percentage still far from the 70% produced by hydroelectric plants, but already close to the 9.3% of biomass plants production, occupy the second place in the national energy ranking.

ABEEOLICA (Brazilian Wind Energy Association) estimates that Brazil, whose installed capacity was 12 GW (2017), has a wind production potential greater than 500 GW [1].

Northeast Brazil is the region with the largest wind energy potential and production, where this energy source accounted for 64% of all the energy consumed in this region as of September 2017. With 135 parks, the Brazilian State Rio Grande do Norte is the Brazilian state, which in 2017 produced more wind energy (3.7 GW), followed by the State of Bahia with 93 parks (2, 4 GW).

As for the wind energy growth in the country, the projection is for an additional 1.45 GW of wind generating capacity in the next six years, only as a result of energy auctions held by the Brazilian government in December 2017.

Although Brazil possesses a vast territory with great possibilities of electric energy generation from the use of the wind source, it currently still generates few power from this source (compared to the use of other sources).

According to the Brazilian Ministry of Mines and Energy, Brazil has an installed capacity of 13.1 GW (in February 2018), corresponding to about 8,3 % of the national electricity matrix.

The Brazilian wind power generation currently comprises 518 wind farms (as of February 2018) and around 6,600 wind turbines throughout Brazil in February 2017.

Few studies have been carried out aiming to define a framework of technical and economic feasibility for the large-scale use of wind energy in Brazil. In this sense, this study is intended to subsidize Brazilian governmental authorities and regulatory agents, potential investors and generators and distributors of electric energy with information, which might assist in the decision to invest in wind generation in Brazil.

1.2 Perspective of wind power generation in Portugal

According to IEP [22] Portugal has ambitious targets regarding the production of electricity, using renewable energy. The European Parliament and the EU Council have set that around 35% of the energy produced in Portugal in 2030 should come from renewable sources. As such, it is essential to ensure that the Portuguese energy mix works with regard to wind and photovoltaic energy. At European level, Portugal is one of the main countries stimulating the energy sector.

As such, according to IEP [22] (…) this is a critical time for wind energy in our country and there is much to be said about its future on the national scene, if we do not see it: an indisputable truth is that the national wind sector is increasingly ageing, and this trend is set to continue".

Being this the tendency to prosper, one way to keep the sector in operation is to extend the useful life of wind generators, in which the oldest have as limit 20 years, given by the manufacturer type certificate.

This fact does not preclude the continuity of operation of the wind generator, however other factors may imply its operation after 20 years. If there is no legislation that ensures the extension of the useful life of the wind turbines, then it is unlikely that there will be continuity in the maintenance of the wind farms based on the safety of all stakeholders in the wind farm.

Currently, in Portugal as reported by IEP [22] there are about 250 wind farms, corresponding to an installed capacity of about 5.3 GW. Of the total number of wind farms, 19% are aged between 15 and 20 years, totaling an installed capacity of 339.52 MW. If there is no investment, the wind sector will decrease drastically over the years.

Assuming that the extension of the useful life of the wind turbines will not be permanent and that all the machines and equipment have an end, it is necessary to envisage the future of wind power plants in Portugal.

Making a predictable short-term analysis based on the year 2018 in only 5 years which corresponds to the year 2023, about 72% of wind farms will be 15 or more years old; making the same analysis, but in a medium term, the scenario is more dramatic according to IEP [22], since in 2028 about 95% of the wind farms will be 15 or more years old, corresponding to 92% of the installed capacity (about 4,90 GW).

There is no doubt that renewable energy is the most favorable trend to produce electricity, as an alternative to fossil fuels, and with Portugal having a high wind load index it is strategic to invest in wind turbines for the generation of electricity.

In this sense, and given that the dismantling of the existing wind parks is unthinkable, two possible solutions are pointed out for their continued operation: 1) the extension of the useful life of wind turbines by means of refurbishing actions, even if for a limited period of time, provided that there is a legal framework for the repowering of wind turbines and 2) replacing the old turbines with more recent, efficient technology and with the advantage of already having the infrastructures for access and connection to the grid available.

1.3 Research objectives and delimitation of the research object

The proposed research aims to achieve three main objectives: (i) to create a database for study purposes, including in this research information such as wind charts, in a five-year retroactive period, installation costs, annual maintenance and operating costs as well as investment on wind equipment; ii) to define planning scenarios for the economic analysis, performance evaluation of wind generation equipment under the operating conditions studied, and the technical and economic data that affect these scenarios and iii) to identify and

define variables that most strongly impact the economic viability of operating equipment and wind farms in Northeast Brazil, identifying the key performance factors for the economic analysis performed, such as technologies, equipment size and productive efficiency.

The study focused on wind turbines with installed capacity above 1MW, capable of generating power at more competitive costs. The research was limited to Northeast Brazil, and more specifically to the federal State of Ceara, by its wind potential in the coastal region of this State and by extensive surveys and studies carried out by local governmental planning institutions and the State University of Ceara (UFC).

The world's largest wind generators manufacturer, the Danish Vestas has also recently released preliminary information based on the study named "SiteHunt® Special Report - The State of Ceara, Brazil", whose data were used in this research, using 'SiteHunt', a software that provides an overview of wind resources and helps defining the site location and layout of a wind farm.

1.4 Project justification

Gradually, the traditional sources of energy generation are being exhausted in Brazil. The progressive use of water resources in the South, Southeast and Midwest has shifted energy production to regions farthest from major industrial and urban centers, increasing the costs of energy generation, transportation and distribution. Thus, in this sense, the generation of wind energy emerges as an important complementary alternative when compared with traditional sources such as hydro and thermoelectricity.

For this reason, in recent years, there has been a strong increase in energy generation in Brazil with alternative sources such as wind and solar energy; between the years 2016 and 2017 there was a 20% increase in wind power generation, corresponding to an addition of 15.6 TWh [1].

Currently, the wind power generated in Brazil is enough to supply about 20 million homes. In 2015 alone, more than 100 wind farms started operating in Brazil, with about 5,2 billion USD in investments generating 41 thousand jobs [2].

This expansion is attracting large international companies that are betting on the growth of this type of energy in Brazil, being currently the fourth country in the world in what concerns the growth of wind energy.

Among all modalities, it was the one that grew the most in 2017, in comparison to other sources of electricity generation. According to the Brazilian Ministry of Energy, in 2017, wind energy represented 8.3% of the Brazilian energy matrix of which, in relation to installed capacity, Brazil is currently ranked 8th in the world ranking. Another 213 wind farms are expected to be additionally in operation in operation in2023, which is expected to make Brazil, one of the six largest producers in the world, in this type of energy.

Thus, to support the decision to invest in the expansion of wind power generation in the country, it is proposed to carry out a comprehensive study that will consider aspects of the technical and economic feasibility of wind power generation and that may subsidize the decision in this mode of investment.

CHAPTER

02 LITERATURE REVIEW

Studies, academic papers and technical reports published on economic feasibility and costs of generating wind energy

2.1 Wind generation worldwide

Wind energy is the most cost competitive renewable energy source. Onshore wind energy is cheaper than any other renewable energy and it is competitive with conventional power generation sources such as coal and gas. According to the European Commission, the Levelized Cost of Electricity (LCOE) of onshore wind ranges from €52 to €110/MWh [3].

When taking into consideration pollution costs and subsidies, which are not included in LCOE (Levelized Cost of Energy) estimations, onshore wind is the cheapest generation source in Europe; offshore wind is on a steady cost reduction pathway with expected costs of €100/MWh by 2020 and €85 to €79/MWh by 2025 depending on projects pipeline.

The above forecast, contained in the document 'The Economics of Wind Energy', published by EWEA [3] has already been surpassed, with wind generation costs in some European countries are currently standing at the level of €50 Euros/MWh.

Not only in Europe but worldwide, wind power is being developed rapidly. In the past 20 years, the global installed capacity of wind power has increased from approximately 1.7 GW in 1990 to surpass the 100 GW mark in December 2008.

From 1997 to 2008, global installed wind power capacity increased by an average of 35% per year and the annual market has grown from 1.5 GW to 20.1 GW at the end of 2008, an average annual growth rate of some 29%. In 2008, global wind turbine investments totaled more than 36.5 billion Euros of which 11 billion (bn) Euros was invested in the EU [3].

Since 2010 more than half of all new wind power was added outside the traditional markets of Europe and North America, mainly driven by the continuing boom in China and India. At the end of 2015, China had 145 GW of wind power installed. In 2015, China installed close to half the world's added wind power capacity.

Several countries have achieved relatively high levels of wind power penetration, such as 39% of stationary electricity production in Denmark, 18% in Portugal, 16% in Spain, 14% in Ireland and 9% in Germany in 2010. As of 2011, 83 countries around the world are using wind power on a commercial basis. Wind power's share of worldwide electricity usage at the end of 2014 was 3.1%.

According to Global Wind Energy Council, as of the end of 2016, the worldwide total cumulative installed electricity generation capacity from wind power amounted to 486,7 MW, an increase of 12.5% compared to the previous year; as reported by Global Wind Energy Council [3], installations increased by 54,6 MW, 63,3 MW, 51,6 MW and 36,0 MW in 2016, 2015, 2014 and 2013 respectively.

As considered by continents, in 2016 the largest installed capacity was in Asia (204,1 MW), of which China (168.7 MW), Europe (161,8 MW), of which Germany (50,0 MW), North America (97,4 MW) of which USA (86,0 MW), and Latin America (15,3 MW), of which Brazil (10,7 MW). In November 2018 Scotland crossed the threshold of wind power supplying 100% of the country's electricity needs [5].

Greater diversification of energy sources, cheaper tariffs and better-quality originated from clean energy for the Brazilian population, this is the perspective for the electric sector in the coming years due to the growth of wind power generation in Brazil, the leader in the production of this type of energy in Latin America.

In Brazil in 2016, according to a ranking published by the Global Wind Energy Council (GWEC) [10], there was an expansion of 2,014 Megawatts in the generation of this type of energy, placing the country in 5th position in the world ranking of installed capacity, last year.

According to ABEEOLICA [3] Brazil occupied the eighth position in the world ranking of accumulated capacity of wind generation (14.7 MW) in 2017, surpassing Canada (12.3 MW) with projections to reach an installed capacity of 19.4 MW in 2023, which refer in

this situation to contracts made possible in auctions already carried out and to be negotiated, in the spot market in the near future.

Brazil has been very proactive in renewable sources, both wind and solar, and has an ambitious program to increase this share of wind energy in the country's energy matrix. Among the top ten wind energy producers in the country, the three largest are located in Northeast Brazil, respectively in the Brazilian federal states of Rio Grande do Norte, Bahia and Ceara.

2.2. Studies and papers published about wind energy feasibility studies

Several studies and papers have been internationally published about feasibility studies of wind generating projects, especially in the last decade. For the purposes of this study, an extensive bibliographical research was carried out on the theme "Studies on Economic Viability of Wind Projects", as shown in Table 2.1.

The researched period covered a period of 34 years (1985-2019), starting with a pioneering work "Study of Wind Energy Utilization in Saudi Arabia", conducted in 1985 by Amin & El-Samannoudy [19].

Among these papers and technical studies, there are technical and economic feasibility studies both related to onshore and offshore generation; these also address the feasibility of both small equipment to be used in agricultural activities and large wind farms with large wind generating equipment, contemplating different techniques and analysis methods: conventional deterministic models using traditional indicators such as Net Present Value and Internal Rate of Return and more sophisticated analysis using Monte Carlo models for electric energy demand estimates. Part of the papers analyzed are shown in Table 2.1, where the publications made in Brazil and abroad were intentionally mentioned separately.

Table 2.1: Papers and Studies published in Brazil and Internationally on Wind Generation Feasibility

Papers and Studies	Authors	Publication Year
Internationally published		
1. Feasibility Study of Wind Energy Utilization in Saudi Arabia	Amin, El-Samannoudy	1985
2. FLOAT –Technical and economic feasibility of a floating wind turbine	Quarton & Hassan	2003
3. Wind Energy Cost and Feasibility of a 2 MW Wind Project	Khambalkar, Gadge, Dahatonde & Karale	2007
4. Economic Feasibility Evaluation of Small Wind Systems in Michigan Agriculture	Komarek	2007
5. Feasibility Study of Developing Wind Power Projects in Iceland: An Economic Analysis	Jónasson	2008
6. Energy return on investment (EROI), economic feasibility and carbon intensity of a hypothetical Lake Ontario wind farm	Endres	2008
7. Wind Feasibility Study	Clark	2009
8. Economic Feasibility Applied to Wind Energy Projects	Oliveira, Fernandes	2011
9. Cost-effectiveness Analysis for Wind Energy Projects	Oliveira, Fernandes	2012
10. Economic feasibility analysis of a wind farm in Caldas da Rainha, Portugal	Oliveira, Fernandes	2013
11. Feasibility Study of Economics and Performance of Wind Turbine Generators at the Newport Indiana Chemical Depot Site	Roberts & Mosey	2013
12. Economic Cost Evaluation on the Viability od Offshore Wind Turbine Farms in Nigeria	Effiom, Nwankwojike, Abam	2016
13. Life Cycle Cost-benefit Analysis of Offshore Wind Energy under the Climatic Conditions in Southeast Asia – Setting the bottom-line for Deployment	Nian, Liu & Zhong	2019
Published in Brazil		
14. "Conceptual Project and Economic Feasibility Analysis of Wind Power Generation Unit in Lagoa dos Patos, RS, Brazil"	Garbe & Tomaselli	2010
15. Economic Feasibility Analysis of Wind Generation Projects in Brazil	Simis	2010
16. "Application of the Activity-Based Costing (ABC) method for the costing of wind farm projects"	Sanford	2012
17. "Study of the Technical Feasibility for the implantation of Wind Farm in the Southwest Microregion of Paraná and West of Santa Catarina, Brazil"	Rossoni	2013
18. Analyses of Wind Energy in the Electrical Scenario: General Aspects and Indicators of Economic Viability	Gomes & Henkes	2015
19. "Analysis of economic and financial viability and risk evaluation of a wind project with Monte Carlo simulation"	Macedo, Albuquerque, Morales	2017

Studies

Though the capital budgeting model is quite useful for evaluating long term investment decisions, it fails in capturing the complexity of the feasibility decisions of many investors. The type of wind turbine selected, turbine height, the turbine's engineering specifications, and meteorological data at the turbine site and other risks related must also be incorporated into the decision model.

Feasibility studies that have been published analyze details such as siting, permits, grid interconnection and energy output in connection to meteorological conditions. There are a variety of models available for calculating the feasibility of utility scale projects, however, small wind projects lack feasibility analysis of a general model.

Komarek [7] estimated costs of generating wind energy with small wind systems in the Michigan agriculture, defining for this study small wind turbines, defined as those with 100 kW or less. According to the author (...) small scale wind can play an important

role in the sustainability of Michigan's agriculture sector and can potentially increase farm profits and decrease incentives to convert farmland to non-farm uses." Some of the literature concerning wind energy economics can be treated in case studies. Such analysis is often technical in nature dealing with the political economy and or technological advancement associated with utility scale wind farms. The author stated that (...) most of the past literature concerning small wind energy is based on site specific studies".

Komarek mentioned that his study intended to provide an integrated general model for analyzing the feasibility of small wind energy projects, specifically using policy options as available to Michigan agriculture producers and that an economic benchmark, such as the Net Present Value (NPV), the internal rate of return is necessary in a capital budgeting model to compare investment scenarios".

Khambalkar et al. [27] published, in 2007, research work about a 2 MW installed capacity Wind Power Project, conducted in the Indian state of Maharashtra. The main objective of the research was to evaluate various costs involved in the energy production.

The cost of energy production per kWh was calculated for the first year of operation. The economics of wind energy and thereby the feasibility of the power project were examined by estimating the per unit cost of energy, Net Present Value (NPV), Benefit-cost ratio (B-C), Internal Rate of Return (IRR), and Pay-back period of the power system. The Discounted Cash Flow (DCF) method was used to find out the IRR ant the project Pay-back.

In the wind energy conversion project, three costs: the installed capital cost, specific capital cost, and life cycle cost of energy, were examined for the evaluation of the production cost of the energy generated.Considering the discount rate on the investment for the project as 7.5 percent, the B-C ratio comes to 3.51 and IRR to 21.82%.

In a paper published in 2015, Oliveira and Fernandes [28] presented cost effectiveness indicators for economic cost analysis of wind projects discussing the concept of Levelized Cost of Energy (LCOE) and proposing the application of the Total Life-Cycle Cost (TLCC) method to wind energy projects. For each indicator studied it was pointed out, in this paper, the project bottlenecks and its application, in the evaluation of wind energy projects.

Effiom et al. [29] in 2016, published research work about an economic cost evaluation on the economic feasibility of producing energy with offshore wind turbine (OWT) farms development in Nigeria, using a 500 MW OWT farm, as an incident study.

A developed model was used in this research to evaluate the economic cost of the OWTs at different phases of the project. Additionally, the effect of the cost drivers at the changed phases of the OWTs was studied correspondingly. Results obtained showed that over 50% of the OWT project cost emanated from capital expenditure while a value less than 50% came from operating expenditure. However, further analysis indicated at a maximum power of 4 MW, a 4.95% diminution in LCOE.

For comparable power rating (PR) between 5 MW ≤ PR ≤ 6 MW, a 2.7% reduction in LCOE exists. The authors point out that cost stability was apparent at a growth of WTs between 300 ≤ WT ≤ 500 MW. The study also observed a decrease in LCOE for all development stages of the OWT while a decrease in the CMS detectability was considered marginal. The authors, subsequently, inferred that Nigeria has the potential for OWT farm expansion.

Nian, Liu and Zhong [30] conducted, in 2019, an interesting study on offshore generation discussing the technical and economic conditions in Southeast Asia and putting this mode of renewable energy resource as an option to address a country's energy and climate objectives without having to occupy large amount of land space.

The authors reported in this paper that (…) wind conditions in Southeast Asia are generally much less favorable as compared to other parts of the world, although several economies in this region consider offshore wind energy as a long term solution to decarbonize the electricity sector and to diversify the source of electricity".

There is according them (…) a need to evaluate the true benefits of offshore wind energy under the region's suboptimal climatic conditions." This study employed the Life-cycle analysis to conduct a Cost-benefit analysis of offshore wind energy in the Southeast Asia context. Findings from the study suggested that the offshore wind energy cost still remained high at that moment of the research for this Asian region.

2.3 Cost of wind energy

Most forms of wind electricity generation require very high capital investment but, on the other hand, low equipment maintenance and no fuel costs. This is particularly true for wind power where the costs of building each high-power wind turbine can reach millions of dollars; maintenance costs are low, and fuel costs are zero.

The composition of the investment and cost calculation of this energy mode considers several factors, such as estimated annual energy production, interest rates, construction, maintenance and location costs, and the risks of the generators falling [5].

Thus, calculations on the actual cost of production of wind energy differ greatly depending on the location of each power plant.

Twenty years ago, the wind power industry has made huge strides, reducing its deployment costs by more than eightfold. Although currently its installation cost is around US$ 1,500,000 per MW of installed capacity, variations in wind regimes and flows show higher degrees of uncertainty than variations in water flow. This is reflected in Capacity Factors of about 35% versus 65% of hydropower.

In Brazil, at the ANEEL auction held on August 27, 2010 (http://www.yahii.com.br/dolar.html), the price of wind energy was R$ 130.8 / MWh (US$ 73,5 MWh) (1 US$ = 1,7716 on this date) being lower than the price of biomass energy and Small Hydroelectric Power Plants (PCHs) [2].

In the auction of August 2011, the price of wind energy reached a new level, even lower, of R $ 99.58/MWh (US$ 62,4 MWh) (1US$ = 1,5956 on this date), getting even cheaper than the energy from natural gas thermoelectric plants. In this auction, more than 1,900 MW were sold, a figure higher than the total installed wind power in the country so far [2].

Thus, wind energy production in the country has doubled since 2014, the year of completion of the projects sold in the above-mentioned auction. The fall in the price of steel, important input to produce wind turbines, also served as an incentive in the short term, propitiating a strong growth and the consolidation of industries specialized in wind generation.

With a growth rate of over 20% since 2001 and new technologies being studied, both power of turbines and tower height have increased. Today most of the manufacturers already commercialize turbines of 2 MW, with an 80 m radius. There are already prototypes of turbines of 5 MW, with 130 m radius.

According to ENERCON [9] - a large German turbine manufacturer -, the average initial investment value for medium and large plants (above 30MW) is R$ 4,200 per installed kW (1,892.2 US$/kW).

In these figures are included the wind generator, civil and electrical infrastructure, all depending on the characteristics of each undertaking, and should therefore be analyzed on a case-by-case basis.

The installation of a wind power plant requires about 18 months, which makes this type of energy generation highly competitive compared to other alternative energy projects, taking an average time period of 24 months to be installed.

Table 2.2: Energy costs comparison values (US$/kWh), year 2014

Hydroelectric Plant	2 - 5
Nuclear	3 - 4
Coal	4 - 5
Natural gas	4 - 5
Wind	5 - 8
Geothermal	5 - 8
Biomass	8 - 12
Hydrogen fuel cell	10 - 15
Solar	15 - 32

Source: American Wind Energy Association Wind Blog – Stanford School of Earth Sciences [6]

Table 2.2 shows an unitary cost comparison (US$/kWh) as of 2014, between different types of energy with values ranging from 2 - 5 (US$/kWh) in the case of hydroelectric plants to 15 -32 (US$/kWh) for solar generating electricity according to [6].

2.4 Investment and capital costs

The capital costs of wind energy projects are dominated by the cost of the wind turbine itself (ex-works). Table 2.3 shows the typical cost structure for a 2 MW turbine erected in Europe. An average turbine installed in Europe has a total investment cost of around €1.23 million/MW. The turbine's share of the total employment cost is, on average,

around 76 per cent, while grid connection accounts for around 9 per cent and foundations for around 7 % of total cost.

The cost of acquiring a turbine site (on land) varies significantly between projects, so the figures in Table 2.3 are only to be taken as an example. Other cost components, such as control systems and road access, account for only a minor share of total costs (less than 1% of the costs).

Table 2.3: Cost Structure of a typical 2 MW Wind turbine installed in Europe (, in 1000 €/MW), 2006

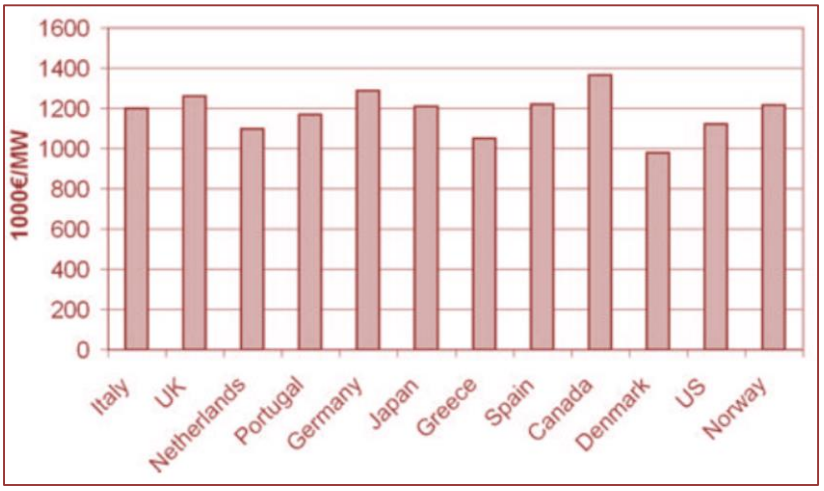
Cost categories	Investment [1000 €/MW]	Total cost share [%]
Turbine (ex-works)	928	75.6
Foundation	80	6.5
Electric installation	18	1.5
Grid connection	109	8.9
Control systems	4	0.3
Consultancy	15	1.2
Land	48	3.9
Financial costs	15	1.2
Road	11	0.9
Total	1,227	100

Source: Calculation based on selected data from European Wind Turbine installation [6].

Wind turbines, including the costs associated with blades, towers, transportation and installation, constitute the largest cost component of a wind farm, typically accounting for around 75% of the capital cost. Wind turbines tend to be type-certified for clearly defined external conditions. The total cost per kW of installed wind power capacity, according to EWEA [6] differs significantly between countries, as shown in Figure 2.1, ranging from around 1,000/kW to €1,350/kW.

The investment costs per kW were found to be lowest in Denmark, and slightly higher in Greece and the Netherlands. For the UK, Spain and Germany, the costs in the data selection were found to be around 20-30 per cent higher than in Denmark. However, it should be observed that Figure 2.3 is based on limited data, so the results might not be entirely representative for the countries involved [6].

Figure 2.1: Total investment cost, including turbine, foundation and grid connection per MW, for different turbine sizes and countries (2006)



Source: Data obtained from EWEA [6]

Also, for 'other costs', such as foundation and grid connection, there is considerable variation between countries, ranging from around 32 per cent of total turbine costs in Portugal to 24 per cent in Germany, 21 per cent in Italy and only 16 per cent in Denmark. However, costs vary depending on turbine size, as well as the country of installation.

The typical ranges of these other cost components as a share of total additional costs are shown in Table 2.4. The single most important additional component is the cost of grid connection which, in some cases, can account for almost half of the auxiliary costs, followed by typically lower shares for foundation cost and cost of the electrical installation.

Thus, these auxiliary costs may add significant amounts to the total cost of the turbine. Cost components such as consultancy and land usually only account for a minor share of the additional costs.

Table 2.4: Cost Structure for a Medium-sized Wind Turbine

	Share of total cost (%)	Share of other costs (%)
Turbine (ex-works)	68-84	n/a
Foundation	1-9	20-25
Electric installation	1-9	10-15
Grid connection	2-10	35-45
Consultancy	1-3	5-10
Land	1-5	5-10
Financial costs	1-5	5-10
Road construction	1-5	5-10

Source: EWEA [6]

Figure 2.2 - Price of Turbine and Additional Costs for Foundation and grid connection, calculated per kW for Selected Countries (Left Axis), and Turbine Share of Total Costs (Right Axis.).

Note: The result for Japan may be caused by a different split of turbine investment costs and other costs, as the total adds up to almost the same level as seen for the other countries. Source: EWEA [6]

Prices of wind turbine, additional costs for foundation, grid connection costs per kW and turbine share on total costs for leading wind generating countries, can be depicted from Figure 2.2.

2.5 Wind Energy

Uneven heating of the earth's surface creates motion of the atmosphere and thus kinetic energy in this movement. Variation in heating and factors, such as surface orientation or slope and rate of reflectivity, absorptivity, and transmissivity also affect the wind resource. In addition, the wind resource can be affected (accelerated, decelerated, or made turbulent) by factors such as terrain, bodies of water, buildings, and vegetative cover.

Wind is air with kinetic energy that can be transformed into useful work via wind turbine blades and a generator. Overall, wind is a diffuse resource that can generate electricity cost effectively and competitively in regions with a good wind resource, high cost of electricity, or both.

2.5.1 Wind Characteristics

Winds vary with the season, time of day, and weather events. Analysis of wind data focuses on several critical aspects of the data—average annual wind speed, frequency distribution of the wind at various speeds, turbulence, vertical wind shear, and maximum

gusts. These parameters allow for estimation of available energy in the wind and the suitability of turbine technology for the site. The wind speed at any given time determines the amount of power available in the wind. The power available in the wind is given by:

$$P = (A \rho V^3)/2$$

where

P = power of the wind [W]

A = windswept area of the rotor (blades)[m^2] = $\pi D^2/4 = \pi r^2$

ρ= density of the air [kg/m^3] (at sea level at 15°C)

V = velocity of the wind [m/s].

As shown, wind power is proportional to velocity cubed (V^3). This matter because, if wind velocity is doubled, wind power increases by a factor of eight ($2^3 = 8$). Consequently, a small difference (e.g., increase) in average speed causes significant differences (e.g., increases) in energy production.

Examining ways to increase the wind velocity at a particular turbine location should be considered through modeling the terrain and micro-siting the turbines. Normally, the easiest way to accomplish this is to increase the height of the tower. The wind industry has been moving toward higher towers, and the industry norm has increased from 30 m to 80 m over the last 15–20 years.

2.5.2 Wind Turbines

Wind turbines consist of rotating blades that convert the kinetic energy of the wind to electric power. They have several moving parts and require regularly scheduled and

unscheduled maintenance. Manufacturer warranties cover the first 2–10 years. Professional wind turbine maintenance contractors are recommended after the warranty period.

Figure 2.3: Large wind turbines installed at Newport, USA.

Source: National Renewable Electricity Laboratory, USA; credit of the photo Joseph Owen Roberts

Wind farms are typically cost effective where the average wind speed and the competing energy costs are high, or with a combination of both conditions. Large wind farms of 100 - 500 MW are commonly deployed because of lower installed costs and mostly due to an overall lower energy cost reduction.

According to Wiser at al [12] in the United States, about 60,000 MW of wind power have been installed until 2012. Turbines are available from as small as 250 W to as large as 5 MW. For the size of the wind plants considered here, large turbines in the range of 1,000 kW to 3,000 kW per turbine would be appropriate.

Wind power became a commercial-scale industry more than 30 years ago. Over that time, wind power has moved from the fringes of the electric power sector to a mainstream resource responsible for 35% of United States new power capacity from 2007 through 2011; according to Williams and Hensley [14] it is second in new capacity additions only behind natural gas power. In the best resource areas or localities with exceptionally high electricity costs, wind power can be cost effective even in the absence of direct financial incentives or subsidies.

As mentioned by Wiser and Bollinger [15] “Technological improvements are expected to significantly lower the life cycle cost of wind energy. Initial investment costs for wind power are relatively high compared to natural gas or other forms of generation; however, with zero fuel costs and relatively modest fixed annual operations expenditures, wind-generated electricity is often a favorable generation resource over the long term”.

CHAPTER 03

METHODOLOGY AND METHODS EMPLOYED IN THE RESEARCH

3.1 Methodological Aspects of the Research

3.1.1 Methodology and Methods used in the research

Goldberg [20] stated in "The Art of Research" that (...) curiosity, creativity, discipline and especially passion are some requirements for the development of a judicious work, based on the permanent confrontation between desire and reality."

The elaboration of a research project and the development of the research itself, be it a dissertation or thesis, should obtain results to be satisfactory, and should be based on a careful planning, solid conceptual reflections and grounded in existing knowledge.

Research is a work in progress that is not fully controllable or predictable. Adopting a methodology means choosing a path, a global course of the spirit. The route often requires reinventing at each step. We need, then, not only rules but a lot of creativity and imagination to perform this work.

Scientific research depends on a "set of technical procedures" to achieve its objectives. In this sense, we can understand Scientific Method as the set of processes or intellectual operations that must be used in the investigation.

Lakatos and Marconi [21] by mentioning the logical bases on which such methods are based mention the main methods that provide the logical basis for research: deductive, inductive, hypothetical-deductive, dialectical, and phenomenological.

From the point of view of its nature, the proposed research is an Applied Research that is the one that aims to generate knowledge for practical application, directed to the solution of specific problems, a Qualitative Research, the type of research that requires the interpretation of phenomena and where the attribution of meanings does not

necessarily require the use of statistical methods and techniques. It is also a research, in which the researcher tends to analyze its data and processes focusing on the process and its meaning.

3.2 Methods employed in the Research

The field research for data collection was preceded by extensive library and bibliographic research on the following topics: wind energy economics, wind energy costs, operation and maintenance costs of wind turbines, economic feasibility studies on the wind generation, Brazilian wind energy market and Brazilian renewable energy market.

A Bibliographical and Bibliometric research was performed using the following data bases: Google Scholar, Directory of Open Access Journals, Open Library, SpringerLink, besides the repositories of the Portuguese Minho and Porto universities.

Deterministic models were used in the analysis of investment projects, which included the elaboration of the Discounted Cash Flow (DCF) and the adoption of indicators such as Net Present Value, Internal Rate of Return and Pay-back, complemented with a sensitivity analysis of the main variables impacting the economic viability of wind investments in Brazil and Portugal.

The Cash Flow analysis allowed the calculation of the break-even for the different variables analyzed, equipment load factor, wind turbine investment and effective hours available for wind generation, among others.

The economic viability analysis of wind power equipment in this study considered the income tax legislation and accounting legal depreciation as practiced in Brazil and Portugal.

In the case of Portuguese legislation, it allows a straight-line depreciation of assets related to wind equipment and respective infrastructure for up to 20 years.

Concerning the Brazilian legislation, the depreciation of wind generators, its depreciation rate and depreciation period is still under study, and for this reason it was

adopted in this study a depreciation period of 10 years equivalent to that of hydraulic turbines (code 8410 of the Brazilian federal revenue service).

Although wind equipment at the end of a considered useful life of 20 years, still has residual value and incur expenses for disposal (wind turbines made of composite material, fiberglass and wood laminate) must be dismantled and destroyed with special environmental care), these revenues and expenses due to calculation difficulties and because they not strongly impact the cash flow, were not considered in the simulation Cash Flow.

3.3 Research Data Sources

The data for the elaboration of Cash Flows under the conditions of economic analysis in Brazil and Portugal, such as investment in the acquisition of wind generators, civil engineering costs in infrastructures (foundations, access roads, electrical connections, etc.), wind generators load factors, wind conditions, were obtained from different sources:

- Working hours and power of wind turbines, load factor, average tariffs practiced in energy auctions in Brazil were obtained in the document "Installed generation capacity in the Brazilian electricity system", published by the Ministry of Mines and Energy of Brazil, in June 2018 [23];

- Capacity and location of installed wind farms in Portugal, installed capacity, number of machines were obtained in INEGI [24] from the document "Wind Farms in Portugal", published by the Institute of Mechanics and Industrial Engineering of the Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering (INEGI), in Dec. 2017;

- Information related to the wind conditions of the State of Ceara, Brazil, its speeds and distributions were obtained in SEINFRA [25] in the document "Atlas Eólico do Estado do Ceara" ('Wind and Solar Atlas of the State of Ceara'), published May 2017;

- Numerous technical bulletins from the Brazilian Wind Energy Association, ABEEOLICA [1], were consulted in the context of this research;
- Other documents produced outside Brazil, such as "Market study: Wind energy in
- Brazil" [26], published by the Ministry of Economic Affairs in The Netherlands, in March 2014, were also consulted.

CHAPTER

04 BASIC COST COMPONENTS OF WIND ENERGY

4.1. Overview of main cost components

As reported before in Section 1, worldwide, wind power is being developed rapidly especially in the last ten years passing from globally installed 100 GW in 2008 to 539 GW in 2017 [10].

Wind power is used in several different applications, including both grid-connected and stand-alone electricity production, as well as water pumping, and these applications influences its generating costs. This report analyses the economics of wind energy primarily in relation to grid-connected turbines, which account for the bulk of the market value of installed wind turbines.

Total costs for installing a commercial-scale wind turbine will vary significantly depending on the number of turbines ordered, cost of financing, when the turbine purchase agreement was executed, construction contracts, the location of the project, and many other factors. Cost components for wind projects include other costs additionally to turbines, such as wind resource assessment and site analysis expenses; construction expenses; permitting interconnection studies; utility system upgrades, transformers, protection and metering equipment; insurance; operations, warranty, maintenance and repair; legal and consultation fees. Other factors that will impact the project economics include taxes and incentives.

Concerning turbines, the largest costs components are the rotor blades, the tower and the gearbox.

Together, these three items account for around 50% to 60% of the turbine cost [6]. The generator, transformer and power converter account for about 13% of the turbine costs, with the balance of "other" costs being made up miscellaneous costs associated with the tower, such as the rotor hub, cabling and rotor shaft. Overall, the turbine accounts for

between 64% to as much as 84% of the total installed costs, with the grid connection, civil works and other costs accounting for the rest [8].

The share of different cost components varies by country and project, depending on turbine costs, site requirements, the competitiveness of the local wind equipment industry and the cost structure of the country, where the project is being developed. Table 4.2 shows typical ranges for onshore and offshore wind farms.

In this chapter, we will be focusing on the basic generation costs of a wind power plant, both upfront (including the lifetime of the turbine) and variable costs, which are mainly for operation and maintenance, since the fuel has no costs.

We analyzed how these costs have developed in previous years and how they are expected to develop in the near future, making a distinction between the short and the long-term costs.

Variables such as investor profit, risk premiums, taxes and institutional arrangements, which also affect investments, should be considered when calculating the final price for wind energy.

For purposes of clarity, we distinguish between the investment cost of the wind farms in terms of capacity installed (addition of upfront/capital costs plus variable costs) and the cost of wind per kWh produced, which incorporates the energy production. Research reports have been focusing on the second category (cost per kWh produced), because it allows comparisons to be made between wind and other power generating technologies.

The main elements determining the basic costs of wind energy are shown below:

- Upfront investment costs, mainly turbines
- The costs of wind turbine installation
- The cost of capital, i.e. the discount rate
- Operation and maintenance (O&M) costs
- Other project development and planning costs

- Turbine lifetime
- Electricity production, the resource base and energy losses

Approximately 75% of the total cost of energy for a wind turbine is related to upfront costs such as the cost of the turbine, foundation, electrical equipment and grid-connections. Fluctuating fuel costs have no impact on power generation costs. Thus, a wind turbine is capital-intensive compared to conventional fossil fuel technologies such as a natural gas power plant, where as much as 40-70% of costs are related to fuel and O&M costs.

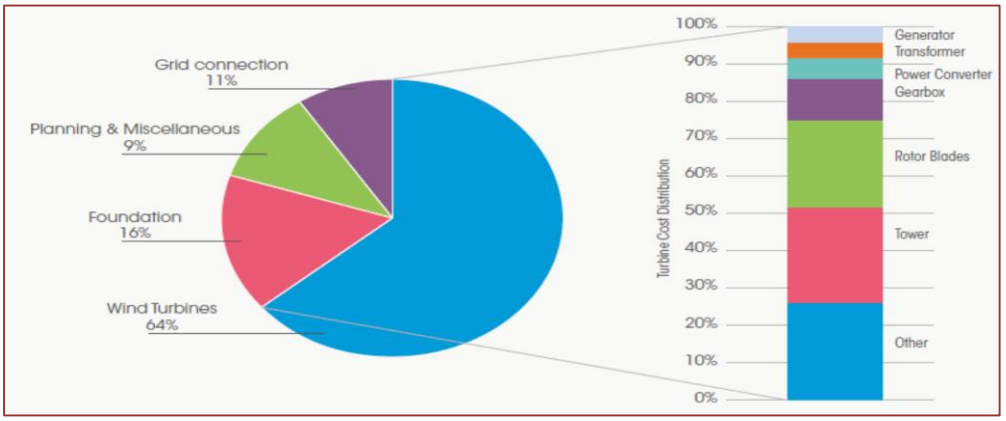
4.2 Upfront capital costs

The installed cost of a wind power project is dominated by the upfront capital cost (often referred to as CAPEX) for the wind turbines (including towers and installation) and this can represent, in some cases, as much as 84% of the total installed cost. Similarly, to other renewable technologies, the high upfront costs of wind power can be a barrier to their uptake, despite the fact there is no fuel price risk once the wind farm is built. The capital costs of a wind power project can be broken down into the following major categories:

- Turbine costs including blades, tower and transformer; [1]
- Civil works costs: including construction costs for site preparation and the towers foundations;[2]
- Grid connection costs: this can include transformers and substations, as well as the connection to the local distribution or transmission network; and [3]
- Other capital costs: these can include the construction of buildings, control systems, project consultancy costs, etc.[4]

[1] Wind turbine costs include the turbine production, transportation and turbine installation.
[2] Grid connection costs include cabling, substation and buildings construction.
[3] Construction costs include transportation and installation of wind turbine and tower foundation and road construction costs and other related infrastructure required for the installation of wind turbines;

Figure 4.1: Capital Cost Breakdown for a Typical Onshore Wind Power System and turbine.



Source: Data obtained from [6]

According to EWEA [6] costs for a utility scale wind turbine ranges from about $1.300 USD/kW to $2.200 USD/kW of capacity installed. Most of the commercial-scale turbines today are 2 MW in size and cost roughly USD 3 to 4 million when installed.

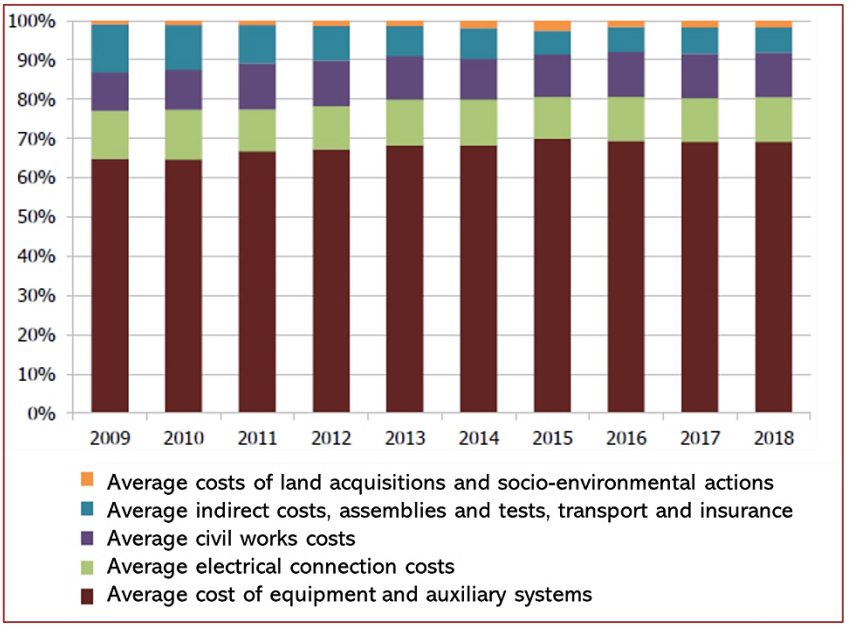
Concerning Brazil, in recent years, costs of wind turbine have been reduced, according to EPE [2] (...) A reduction in average investment costs by bidders in the years 2006/2007 in the energy auctions is observed, followed by a stabilization. It should be noted that the small number of wind projects registered in the years 2007 and 2008 led to a small sample and, therefore, a small variation of costs. Already in the following years, from 2010 to 2014, there were wide ranges of variation, highlighting the very low minimum values."

Still according to EPE [2], more recently it can be observed that (...) a narrowing of these bands, which can be explained by the maturation of the sector, with costs better known by agents. The investment costs of the projects eligible to participate in the last 2018 quarter auctions, according to 'entrepreneurs' statement, were estimated in the range of USD 801/kW (R$ 3,100/kW) to USD 2.224/ kW (R$ 8,600/kW), with exchange rate quoted at 3,8677, in 30/11/2018. Due to the high index of nationalization of equipment, there was no significant impact of the exchange variation on the costs of the projects, which are more sensitive to the inflation variation in the period."

[4] Other capital cost in this context include development and engineering costs, licensing procedures, consulting and permits.

Figure 4.2 as indicated by EPE [2] shows (...) the average division of investment costs of authorized projects in Brazilian currency R$/kW, by cost categories, as presented in the projects data sheets. The equipment corresponded to the greater part of the costs, about 70%, and variations in these average compositions were observed over time, despite the equipment changes, previously discussed". For the purpose of USD conversion into Real (Brazilian currency), the parity R$ - USD, on the date of July 1, 2014 was considered.

Figure 4.2: Relative Weight of Wind Investment Costs.

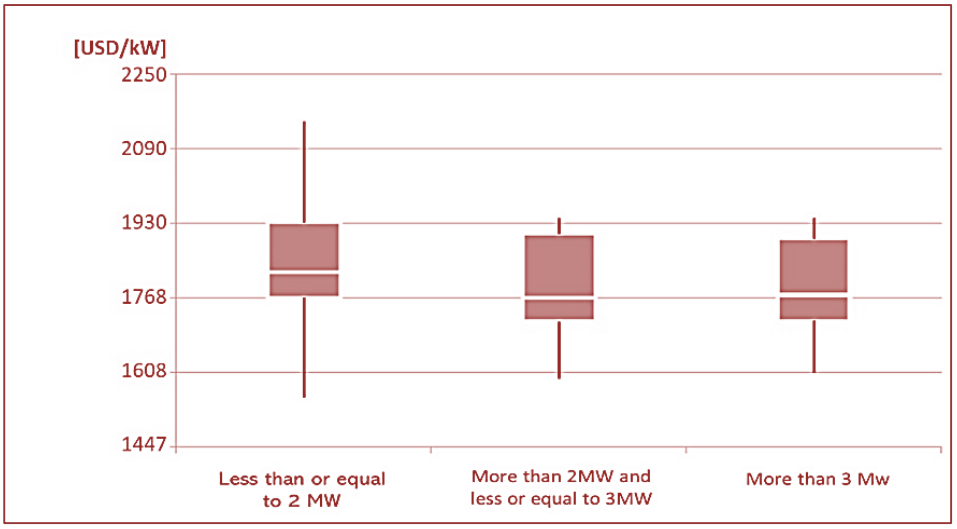


Source: project Data obtained from [2]

Given the relevance of the wind turbines costs on projects total cost, a more detailed analysis on them is worth.

Figure 4.3 indicates the average specific costs, per turbine power range, considering the sample of projects qualified for the A-6 auction of 2017, showing that the lower capacity equipment has, on average, higher costs in USD/kW.

Figure 4.3: Investment Cost per Turbine Unit Power (USD/kW).



Source: Data obtained from [2]

For smaller wind turbines, there is a greater variation in costs, which can be explained, at least partly, by a temporal question. As already shown, in the first energy auctions held by the Brazilian government predominated equipment of lower power so the budgets had a great variation. In recent years, machines with power above 2 MW predominate and total budgets converge towards a lesser range of costs.

4.3 Grid connection costs

Wind farms can be connected to electricity grids via the transmission network or distribution network. In the former case, transformers will be required to step-up to higher voltages than if the wind farm is feeding into the distribution network, what tend to increase costs.

If the grid connection point is not far from the wind farm, a high voltage alternating current (HVAC) connection is normally provided. Over longer distances it may make sense to use a high voltage direct current (HVDC) link, as the reduced losses over this link will more than offset the losses in converting to direct current and back again to alternating current.

In the United States, it has been estimated that HVDC connections will be attractive for distances over 50 km in the future (Douglas-Westwood, 2010).

Grid connection costs in 2006, according to EWEA [6], amounted to about 9.0% of the cost structure of a 2 MW Wind Turbine. Grid connection costs are an important part of the initial site selection and of the cost analysis. In the feasibility study, the detailed layout and component-choice is determined:

- If the low voltage distribution grid (e.g. 15 kV grid) is the closest available solution, on the other hand this solution implies expected increase of electrical losses, voltage drops due to reactive power;

- Compensation has to be taken into account for the calculation of electricity delivered to the grid by projects.

- Another possibility is the consideration of the construction of a new substation at the wind park area, where a high voltage single overhead transmission line brings the generated electricity into the existing high voltage grid what causes significantly higher investment cost but on the other hand, reduces expected electrical losses.

- If the connection should be realized via an existing substation, the remaining capacities of this substation should be checked. There may be a need to extend the capacity of the existing substation and this and this may entail additional costs;

- As an alternative of using overhead lines, a grid connection via underground cables can be considered.

- Feed-in characteristics of the selected wind turbines are described. Modern wind turbine (pitch-concept wind turbine) installations feature a grid feeding system that meets the latest grid connection requirements and can be therefore easily integrated in any supply and distribution structure, especially when stipulated requirements, such as voltage frequency and reactive power for each individual turbine in a wind farm have to be considered in order to provide reliable economical grid operation, power feed timing has to be regulated

Based on these considerations a wind park grid connection layout must be developed and related costs should be used in the Financial analysis.

4.4 Tower Foundation Costs

Foundation costs can have strong variations depending on the soil conditions, the tower height and weight of the generator and rotor. A turbine foundation usually is very large: 8-20 truckloads of concrete, and in the case of wind turbines installed in the United States, costs ranges from $100,000 to $250,000 including service of soil boring and engineering design.

According to Svensson [11] the choice of a foundation method is dependent on many parameters, (…) and it is hard to decide when a specific method is the most appropriate. Generally, it is the most cost-efficient solution that is chosen, given that the safety can be granted. When calculating a budget for the construction of a foundation there are almost unlimited number of costs that must be considered". The factors listed by the above-mentioned author, is of major importance due to:

- The site availability specially in remote locations and in case there is no road leading to the construction site;

- The amount of material required: the volume of concrete and the amount of reinforcement, number of piles, pile material, etc.;

- The designing and construction work, especially when extensive excavation is necessary;

Svensson [11] points out that (…) The foundation's only task is to ensure the stability for the wind turbine, and to do so over its lifetime. This is done by transferring and spreading the loads acting on the foundation to the ground. The vertical force acting on the foundation is mainly dead load from the tower, the nacelle and the rotor blades, but the wind may also give arise to some vertical force." Still according to Svensson [11], the most significant loads on the foundation origins from the wind load.

Due to the normally great height of the tower, a horizontal force from the wind is giving a considerably big bending moment at the foundation. The tower usually has got the form of a hollow truncated cone and is made of high-quality steel. The wide tower base connects, the prefabricated tower, to the in situ made foundation via an interface.

It should be mentioned some possible solutions of this interface: building a giant steel pipe with a flange, embedded in the concrete foundation or constructing "*a bolt cage*", where several long bolts are embedded in the concrete.

4.5 Capital costs, remuneration and depreciation - capital costs of Installed wind power systems

The installed cost of wind power projects is currently in the range of USD 1. 700/kW to USD 2.150/kW for onshore wind farms in developed countries [12], [13] However, in China, where around half of recent new wind turbines was added, installed costs are currently just USD 1.300/kW.

Although global time series data are not readily available, data e.g. for the United States show that installed costs declined significantly between the early 1980s and 2001. Between 2001 and 2004, the average installed cost of projects in the United States was around USD 1,300/kW [12].

However, after 2004 the installed cost of wind increased steadily to around USD 2 000/kW according to 2010 and 2011 data, suggesting that a plateau in prices may have been reached. The reasons for these price increase according to the above authors are of several natures, and include:

The rapidly rising cost of commodities in general, and steel and copper prices. In offshore projects, copper and steel alone can account for as much as 20% to 40% of the total project cost.

The shift to offshore developments may be raising average installed costs in Europe. This is being accelerated by the shift from a shallow water market driven by Denmark to deeper water projects in the United Kingdom and Germany.

Market demand grew so rapidly that the supply chain and human capacity required had difficulty keeping up with demand and shortages in certain components – notably, wind turbines, gear boxes, blades, bearings and towers – and led to higher costs. The increasing sophistication of turbine design, component integration and grid interaction also pushed up prices.

The plateau in data for the United States suggests that for onshore wind installations, the supply chain has progressively caught up with demand, aided by more stable (but still volatile) commodity prices. Increased competition at a global level is also helping, especially the emergence of manufacturers with significant local content in countries with low-cost manufacturing bases.

For offshore wind, the market is still quite immature and mainly located in Europe. Costs for offshore wind projects vary but are in the range 3,300 – 5,000 USD /kW. This market was shared by Vestas and Siemens in 2010 and by Siemens and Bard in the first half of 2011. However, the average turbine installed in Europe has a total investment cost of around €1.230 /MW.

As it can be seen in Table 1.2, the turbine's share of the total cost is, on average, around 76%, while grid connection accounts for around 9% and foundation for around 7%. The cost of acquiring a turbine site (on land) varies significantly between projects, so the Figure in Table 1.1 is to be taken as an example. Other cost components, such as control systems and land, electric installation, consultants, financial cost, road construction and control systems add to the investment cost.

According to EWEA [6] the total cost per kW of installed wind power capacity differs significantly between countries inclusive in Europe. The cost per kW typically varies from around Euros 1,000/kW (USD 1.120/kW) to Euros 1,350/kW (USD 1512/kW).

In the case of the Brazilian Market, more recent data from the Brazilian Energetic Enterprise shown in the document "Participation of Wind Business Ventures in Energy Auctions in Brazil", point to values ranging from 1.630 USD/kW (turbines with power capacity less than 2,0 MW to 1,570 USD/kW) in case of turbines with power capacity in the interval 2.0 – 3.0 MW according to EPE[2].

In Europe, as shown in Figure 1.1, the investment costs per kW were found to be the lowest in Denmark, and slightly higher in Greece and the Netherlands. For the UK, Spain and Germany, the costs in the data selection were found to be round 20-30% higher than in Denmark.

Also, for "other costs", such as foundation and grid connection, there is considerable variation between countries, ranging from around 32% of total turbine costs in Portugal,

to 24% in Germany, 21% in Italy and only 16% in Denmark. However, costs vary depending on turbine size, as well as the country of installation, distance from grids, land ownership structure and the nature of the soil.

The typical ranges of these other cost components as a share of the total additional costs are shown in Table 1.3. In terms of variation, the single most important additional component is the cost of grid connection that, in some cases, can account for almost half of the auxiliary costs, followed by typically lower shares for foundation cost and cost of the electrical installation.

Thus, auxiliary costs may add significant amounts to the turbine total cost. Cost components such as consultancy and land, usually only account for a minor share of the additional costs.

Grid connection can in some cases account for almost half of auxiliary costs, followed by typically lower shares for foundation cost and cost of the electrical installation. These three items may add significant amounts to the total cost of the projects. Cost components such as consultancy and land normally account for only minor shares of the additional costs.

4.6 Land Lease

Wind projects should be sited in the windiest areas to maximize revenue from electricity sales and production incentives. Generally, this requires obtaining a lease for the land the project will be sited on as well as obtaining wind easements on adjacent land. This is to prevent other projects from being constructed too closely to your project, which would lower its production numbers.

Generally, leases for megawatt-scale turbines will range from $3,000-$12,000 per turbine per year depending on their size, the wind resource in the area, and land amount required for the construction.

Many wind developers in the United Sates are paying a fixed amount per installed MW (USD 2,500-$4,000), which increases every year at either a fixed percentage or at the

Consumer Price Index rate of increase. Landowner payments can also be structured as a percentage of the production revenue from the project.

4.7 Permits

Wind projects need to perform environmental, archeological impact, and other studies before permits to build are issued. State permitting agencies may also require other studies and fees. Common permits are building, conditional/special use and road access.

The local and/or state zoning authority will be able to help you determine what permits your project will need to obtain.

Legal costs in permitting can get expensive for projects in areas where possible litigation might occur from parties affected by the project. Often a building permit fee is based on total project cost and in the case of the United States can easily amount to USD 5,000-$10,000 per turbine; the cost to hire consultants and complete the required studies can range from USD 5,000-$50,000 for a single turbine project.

4.8 Connectivity

It is imperative to research the interconnection process early in the planning phase because the process can be very time consuming and the interconnecting costs can be prohibitive for a project.

Interconnection studies for a project, in the United States, can cost from USD 5,000 - 150,000 or more, depending on the project size and the interconnection point. Three-phase lines are required for large generators, but you cannot assume that any three-phase line can carry the power from turbines.

Significant unanticipated costs may be incurred if the power line near the site does not have the capacity to handle more electricity. In other words, we need to check whether nearby power lines are “full.” Transmission lines are expensive to build and difficult to

site. If there is available capacity on the transmission lines near the site, we will likely need to build feeder lines from the wind farm installed to the transmission lines.

Feeder lines usually cost $70,000 - $90,000 per mile and operate at a higher voltage (typically 12 kV, 24 kV or 34.5 kV) than what the generator creates, requiring a step-up transformer at the base of each wind turbine.

The cost of the transformer ranges from USD15,000 - $50,000 for each turbine. Some wind turbines and transformers come as a package and can be discussed in detail with the turbine manufacturer. At the point the electricity is transferred from turbine ownership to the utility's (i.e. the interconnect point), you will be responsible for paying for all the equipment that the utility requires to make a safe and stable interconnection. This equipment includes:

- Switches that can disconnect energy lines;
- Relays, breakers, and fuses to protect the power system, should there be an electrical fault;
- Metering to tell the utility how much the plant/generator have generated and added to their system;
- Various other electrical structures and or devices;
- Electrical wire, which can often be the most expensive part of the electrical connection. With the high cost of copper and aluminum, the wires running down the tower alone can cost more than USD 20,000 for a larger generator.

The interconnection study will outline what impact your project will have on the power system. The results of this study may require that the project pay for significant system upgrades to mitigate these issues. Interconnection upgrades can cost in the thousands to hundreds of thousands of dollars. The company generating electricity should work with an expert through the interconnection process to make sure that the utility is not adding unnecessary additional costs to the proposed upgrades, making it difficult for the company to develop the project.

If a smaller project can interconnect onto a distribution line (usually less than 25kV), then it can benefit from a lower cost interconnection without the necessary substation (avoiding deployment costs increase) connecting it directly to power lines.

Distribution lines are the lines that bring the energy to the customer, whereas transmission lines are for transmitting electricity from point to point using higher voltages to minimize line losses.

For instance, a 6 MW project connecting to a 69kV transmission line will require building an interconnection substation with costs in excess of $1million dollars according to specialists. The same 6 MW connected to a distribution system can cost one-fourth this amount in interconnect fees.

A new dedicated transmission line for a project can cost an excess of USD 200,000 per mile. The utility may also make recommendations for additional system features that are not required and may or may not be beneficial to your project. For example, the utility might advise to put in a “dual line feed” to avoid them curtailing your turbine for those few days a year they need to do line maintenance. The dual line is a second, redundant line that allows the project to generate power even if the first line is taken out of service. Evaluating the cost effectiveness of a dual line feed is part of the economic analysis.

CHAPTER

05 FEASIBILITY STUDIES OF WIND ENERGY PROJECTS

The term *Feasibility Study* used in this research, relates to wind energy projects and is used for assessments of technical and economical nature. Feasibility studies include, among others, the results of wind measurements (assessing wind potentials). If these results indicate that technical and economical operation of wind energy (projects) can be considered viable, a feasibility study should be conducted [16].

According to GTZ [17], under consideration of a wind resource appraisal and other relevant inputs, a feasibility study is normally conducted in order to:

- Determine the optimum size of the wind turbines under the technical and transport infrastructure conditions;
- Optimize the technical lay-out of a wind park site;
- Assess the comparative economic and financial viability of a project and propose a implementation decision.
- EWEA [5] proposed main contents for a feasibility study as detailed below:
- Technical aspects already regarded during the pilot study must be assessed in a more detailed manner, including on-site wind monitoring to determine a draft design and layout for the installation;
- An economic assessment is conducted to establish the economic and commercial viability of the project;
- An appraisal and scoping exercise to identify specific environmental constraints and opportunities must be implemented;

- Possible planning constraints are then assessed.

The economic assessment of a wind park viability includes important tasks to determining economic parameters and variables of a wind project [17].

- An energy production estimation to define expected project's revenues;

- A comprehensive and detailed estimate of the costs (investment, operation and maintenance, costs of project development);

- An economic assessment of project benefits concerning economic development and gains outside the project, inclusive environmental gains;

- A financial analysis based on the estimation of costs including a cost-benefit analysis, which allows an exact statement concerning investment returns. Discussion and evaluation of different operation models should be included.

The project appraisal related to environmental and social constraints should be based also on an open dialogue with the affected population and planning authorities [6].

5.1 Detailed Assessment of Site Conditions

Assessment of site conditions starts with a general description of the area proposed for the project: The altitude above sea level, the orographic conditions as well as the surface properties (e.g. plants, infrastructure) are important information to be included in the site description. Site limitations like domestic dwellings, important roads, nearby airports or telecommunications facilities for the wind park area must be identified in order determine the wind park layout.

A central aspect is the analysis of ground and soil conditions to choose the necessary basement types for the individual turbines and related foundation costs. The local geology site should be described in general terms and the seismic conditions at the site investigated, if there is a potential earthquakes risk in the area.

Distance to city infrastructure and ports is another issue to be considered, because in most cases turbine parts must be transported to project sites via roads.

Road conditions especially the stability for heavy freight, inclination and curve radians are important for transport of long heavy parts of wind turbines. Often the feasibility of transport for turbines of capacities over 2 MW is assessed separately. Available crane capacities in the project country should be checked.

At the point the feasibility study is conducted, an environmental impact assessment must have been carried out and the environmental constraints must be used in the project layout development [16].

For information about possible legal constraints of the project development, a central task is to identify conflicting interests with other land users (e.g. mining activities, recreational).

5.2 Wind Resources

The description of the wind resources for a feasibility study includes a detailed description of the measurement campaign, which has been conducted for project development. Mast positions used, measuring technology like anemometers and data loggers as well as their application should be described carefully to provide a reliable information basis for projects appraisal. Besides wind resources further data like temperature or air density should be presented in the feasibility study.

The wind resources outcome should be presented as a list of average wind speeds per wind direction (usually wind direction is divided in sectors of 30°) as well as their frequency distribution. A very important step for rating the available wind resources is the wind data analysis. Primarily quality of data must be checked carefully concerning erroneous values, which must be sorted out or replaced by suitable ones. Data losses over longer periods of time may distort the information[16].

Also measurement campaigns for wind park planning are conducted for a minimum of one year; the results can be regarded as representative for an estimation of energy yields during common wind project lifetimes of 20 years, because wind conditions are not stable over the years and oscillate around in the long term. For this reason, a

correlation analysis of the collected data with long-term data gathered from other local sources must be conducted.

If long-term data is available, gathered wind data of the measurement campaign can be adjusted considering these values. According to international standards, this must be done by comparing and adjusting the measured wind data by means of suitable mathematical methods/models with data obtained from long-term measurements - usually from meteorological stations. A period of at least 10 years (15 to 20 years is preferred) can be considered as an adequate longtime experience[17].

Wind turbines are subjected to environmental conditions which may affect their loading, durability and operation. To ensure an appropriate level of safety and reliability, the environmental parameters should be considered during the selection of appropriate wind turbines. The categories used to describe wind turbines suitable for certain site conditions are the so-called IEC-classes[18].

5.3 Technical Layout of Wind Parks

Based on the long-term corrected wind data a wind potential map must be calculated for the feasibility study using analysis software (e.g. WindPro and WASP). Considering this map and the outcome of measurement campaign and data analysis the appropriate wind turbine type is selected. Usually several scenarios using different sizes, numbers and turbine types are considered, and their cost and benefits must be considered during the financial viability assessment of the project.

The following criteria are used to determine appropriate wind turbine types[15]:

- Transportation to the foreseen wind park site.
- Available space on site.
- Topographical conditions on site which may prevent the installation of larger turbines in the Megawatt - range.
- Local experiences with regular operation and maintenance with wind turbines.

- Distances between site and turbine manufacturer who will perform the maintenance within the warranty period.
- Wind turbines types yet installed in the county.
- Energy Yield.
- Turbine types available on national markets.

Besides turbine type and capacity, the suitable tower heights are chosen considering the local wind profile (increase of wind speed with height). Higher towers can exploit higher wind speeds so that the annual energy production can be increased correspondingly. The counteracting effect is the respective additional investment cost for the tower and the foundation[16].

For the micro-siting certain minimum distances between the individual wind turbines must be observed. A common rule of thumb specifies three to five rotor diameters in cross wind directions (less than three is possible under some circumstances) and six to eight rotor diameters in main wind direction as a minimum spacing between the individual turbines.

Based on the analysis concerning turbine type, capacity, hub height and optimal distances between the towers, several wind park layouts are compared regarding their expected energy yield and investment costs.

These layouts are additionally influenced by noise assessments and shadow impact of the proposed wind farm: The target of the noise assessment is to investigate the potential noise impact of the wind turbine operation on sensitive areas in the vicinity of the wind farm[17].

When the sun is just above the horizon, the shadows of the wind turbine generators can be very long and can move across houses (windows) for short periods of time. If this happens for longer period, it causes stress to the inhabitants. Thus, the shadow impact

of a certain layout has to be reduced until no significant disturbance should be expected[18].

An important part of the wind park layout is grid-connection, consisting of the implementation of an internal cabling concept and the technical design of the grid connection point. Optimization of cabling and grid-connection can be an important influence for park layout[19].

5.4 Energy Production Estimation

The calculation of the wind resources on-site and the corresponding energy production are based on the assessment of wind potentials by anemometric measurement. The wind data is processed by software packages to calculate the expected wind energy yield for the proposed site.

This calculation by software packages like 'WindPro' and 'WASP' combines a great number of characteristics (site conditions and wind speed distribution)[20]:

- Orographic description and roughness values as a quantitative description for the friction of the surface causing a slowdown of the near-surface air flow valleys and similar terrain structures as an influence on wind speed differences within the proposed wind park area. For instance, valleys can act as a blast pipe, concentrating the air flow.
- Wind shear as determined by measurement of wind speed in different heights and mathematic extrapolation
- Wind turbine parameters and the corresponding power curves of all proposed turbine types; scenario analysis for the different turbine types are worked-out and
- Air density.

In a reverse process, the generalized regional wind climate is then applied to topography, surface description and obstacles at the vicinity of each individual wind turbine, providing the wind flow at this point even if the wind data has measured in some distance which can be, depending on the terrain, up to several kilometers.

A very important aspect of production energy estimation for use within a feasibility study is the determination of potential losses and uncertainties caused by uncertainties in variables and parameters of the used model.

Meteorological phenomena can only be predicted to a certain limited degree. Therefore, it is not possible to make an exact forecast of the wind conditions even if long-term reference data are used. According to GTZ [31], wind conditions and other uncertainties, should also be considered in the energy production estimation:

- Turbine Availability - describes the percentage of a year (i.e. 8760 hours) where the turbine can generate electrical energy while being connected to the grid;
- Electrical Losses - the electrical losses depend on the resistance of the conductors and on the current intensity;
- Wind Speed and related uncertainties;
- Uncertainties of Wind Data

The estimation of energy yield as well as the corresponding uncertainties are calculated for several scenarios to allow extensive comparison before a layout is implemented.

5.5 Grid Connection

Considerations concerning opportunities of grid connection are an important part of the initial site selection and of the cost analysis. In the feasibility study, the detailed layout and component-choice is determined:

- If the low voltage distribution grid (e.g. 15 kV grid) is the closest available solution, it is expected an increase of electrical losses, voltage drops and necessary reactive power;
- compensation have to be taken into account for the calculation of electricity delivered to the grid by the project;

- Another possibility is the construction of a new substation at the wind park area, where a high voltage single overhead transmission line brings the generated electricity into the existing high voltage grid. This option causes significantly higher investment cost, but reduces expected electrical losses on the other hand;

- If the connection should be realized via an existing substation, the remaining capacities of this substation should be checked. There may be a need to extend the capacity of the existing substation;

- As an alternative of using overhead lines, a grid connection via underground cables can be considered;

- Feed-in characteristics of the selected wind turbines are described. Modern wind turbine (pitch-concept wind turbine) installations feature a grid feeding system that meets the latest grid connection requirements and can therefore easily integrated in any supply and distribution structure, especially when stipulated requirements, such as voltage frequency and reactive power for each individual turbine in a wind farm have to be considered;

- In order to provide reliable economical grid operation, power feed timing must be regulated.

Based on these considerations a principle wind park grid connection layout is developed and related costs can be used in the Financial analysis.

5.6 Wind Costs Estimation

This part of feasibility studies gives a structured overview of all costs related to wind project development and implementation. The costs are usually calculated and listed separately for:

- Investment costs;

- Costs of the construction period (costs of wind turbine erection and infrastructure installation at the site), and

- Operation and maintenance costs

An exact determination of project costs respectively the calculation of uncertainties in cost development form is the necessary basis for conducting the central cost-benefit analysis for the appraisal of the financial project feasibility.

5.7 Capacity of Credit (CC)

Any kind of electrical power plant is required to answer the crucial question: To what extent is a specific energy production unit with an installed nominal capacity available to meet system demands?

Typically, the answer is derived from a statistical analysis of this period, when a unit or technology is not available, even if it is supposed to be working, generally termed as forced outage. For conventional generation units this is mainly a technical question, whereas for intermittent resources like wind, solar and hydro power, it is a question of fuel availability: is wind, water or solar radiation available when it is needed? And if yes, what amount is available and how does the intermittency influence the rest of the electrical supply system? The answer is given by the capacity credit, which should consider each of the posed questions.

There are various definitions of the term capacity credit (CC), and several synonyms are used in parallel, each bearing a similar variety of definitions. The two most common synonyms of CC are "firm capacity" and "capacity value".

The CC can be defined as the firm capacity, which can be replaced by a certain amount of installed wind power or any other energy source. It can be used either as a value in MW or as a percentage of the installed wind capacity. This is the terminology used in recent studies throughout industrialized countries, where wind energy is replacing other forms of energy. In developing countries, which pursue high goals for improving the electrification rate, it is important to analyze how much capacity wind energy can add to the current system.

5.8 Economic Analysis

According to the "World Bank Handbook for Economic Analysis of Investment Operations", the main purpose of an economic analysis is to help designing and selecting projects that contribute to the welfare of a country. Whereas the financial analysis evaluates the project from the point of view of the operating company or Independent Power Producer (IPP), the economic analysis should evaluate the project from the point of view of the whole economy of the country.

In this case, the purpose of the investigation is to compare from the macroeconomic perspective the benefits of a project with the costs incurred.

The standard evaluation for costs and benefits must be done under a monetary quantification. To the greatest possible extent, the project impacts are evaluated in terms of economic market prices.

Shadow prices are employed, i.e., internal accounting prices that free the day-to-day (market) prices from multifarious biases. In other words, shadow prices represent an attempt to illuminate the actual costs of a product or service for the economy. In comparison with micro- and macro-economic prices, shadow prices are devoid of taxes and charges, duties and subsidies.

5.9 Clean Development Mechanism Assessment

Developing countries and transition economies may host a project and benefit from CDM as an additional co-financing source. Project sponsor can be either the host country or usually a project sponsor.

In the case of a wind energy project, for instance, the owner of the wind park generates revenues from electricity sales in the national market and from the sale of Certified Emission Reduction (CER) credits. CERs can be sold to carbon exchanges or to a CER acquisition program such as a carbon fund.

Carbon funds offer the opportunity to project owners to close an Emission Reduction Purchase Agreement (ERPA) for the whole CER crediting period, usually 10 years, which avoids risks of oscillating CER market prices.

A potential buyer for the CERs generated by a wind park project could be found, for example, through the Community Development Carbon Fund of the World Bank, which links small scale projects seeking carbon finance with companies, governments, foundations, and through NGOs looking for improvement of livelihoods in local communities and obtain verified Emission Reductions.

To make CDM accessible as a source for project funding, the emission reductions generated by the implemented project must be calculated.

For that purpose, assumption for a baseline are made: the amount of emissions which would occur if the project did not take place - is of crucial significance for the amount of credits a CDM project can generate.

The amount of CERs issued for a project equals the difference between the actual emissions and the baseline. For inclusion of this additional funding into the financial analysis potential revenues of selling generated CERs must be estimated.

5.10 Financial Analysis

This financial analysis is intended to clarify whether the wind farm project is financially feasible for the described parameters. And whether or not and, if so, how the financial efficiency threshold can be reached and surpassed and, if so, how by which means of technical and non-technical modifications.

The main difference between a financial analysis and an economic analysis is that, in the financial analysis, the wind farm is viewed as an enterprise and in the economic analysis the windfarm is evaluated from the point of view of the national economy of the country. In the financial analysis, the windfarm operating company must earn enough money, by feeding electricity into the existing grid, to cover its operating costs, interest payments, loan payments and distribution of dividends to equity investors. The object of consideration can be of commercial or microeconomic nature [30].

5.11 Framework Analysis for Wind Energy

The general relation between equity and debt for the realization of projects is an important issue to be analyzed. Potential funding sources to cover investment costs must be identified and the projects financing concept described.

For the calculation of project returns and viability the regulatory and legal framework is analyzed: Country-specific conditions for the development of wind energy projects are based upon the policy framework conditions prepared by national or regional governments.

The financial feasibility of any wind energy project proposed to sell electricity to the grid depends on the available framework conditions for support. Inadequate or non-existent framework conditions often form crucial barriers impeding the exploitation of available wind energy potential. According to GTZ [31] , the existence, operability and reliability of a feed-in tariff system must be checked and integrated in the financial viability assessment.

CHAPTER

06 CASH FLOWS AND RESULTS DISCUSSION

6.1 The Cash Flow elaboration

The economic analysis was performed using conventional Cash Flows, which considered parameters as used in traditional economic viability deterministic models, such as Net Present Value (NPV), Internal Rate of Return (IRR) and Pay-back followed by a sensitivity analysis of the variables; additionally, we have adopted the US Dollar as our monetary reference.

In the case of amounts originated in Brazilian Real and Euros, these were converted into the American currency at the parity on the date they were generated. In order to analyze the economic viability of wind power projects, in Brazil and Portugal, in context of this research, four cash flows were prepared, considering technical and tax aspects:

- Cash Flow 1 according to Brazilian technical and tax parameters, 20-year life span and 20-year straight-line depreciation period (see Appendix 1);
- Cash Flow 2 according to Portuguese technical and tax parameters, 20-year life span and 20-year straight-line depreciation period (see Appendix 2);
- Cash flow 3 according to Brazilian technical and tax parameters and a 5-year straight-line depreciation period (see Appendix 3);
- Cash flow 4 according to Brazilian technical and tax parameters, 20-year life span and a10-year straight-line depreciation period (see Appendix 4).

The above four cash flows are reproduced as appendixes to this research report. Table 6.1 shows the main differences among the cash flows considered in the economic feasibility analysis of wind generating projects for Brazil and Portugal.

Table 6.1: Cash Flows used for the economic feasibility analysis of wind generating projects in Northeast Brazil and Portugal

Feasibility Calculation Parameters	Cash Flow 1	Cash Flow 2	Cash Flow 3	Cash Flow 4
1. Interest Rate [%]	7.3%	8%	7.3%	7.3%
2. Revenue Yearly [USD]	407,340	394,200	407,340	407,340
3. Turbine Power [MW]	3	3	3	3
4. Tariff [US$/MWh]	31	50	31	31
5. Load Factor [%]	50%	40%	50%	50%
6. Generated energy yearly [MWh]	13,140	10,512	13,140	13,140
7. Hours Available Annually [h]	8,760	8,760	8,760	8,760
8. Wind Turbine Investment per installed power [USD/kW]	761	761	761	761
9. Turbine acquisition cost [US$ x 1000]	2,283	2,283	2,283	2,283
10. Civil works and infrastructure [in % of turbine cost]	0.25	0.25	0.26	0.27
11. Total Costs - Turbine and installment costs [USD x 1000]	3,040	3,040	3,040	3,040
12. Straight-line depreciation [years]	20	20	5	10
13. IRS corporate tax rate	27%	28,9%	27%	27%

Although there is a difference in relation to the cost of wind turbines and works in projects being implemented in Brazil, in similar equipments and works already implemented in Portugal, in the absence of detailed data and more precise budgets, we have adopted international values for the implementation of wind power equipment for both countries Brazil and Portugal.

6.2 Wind Generating Projects and Financing Conditions in Brazil

6.2.1 Interest and financing rates

Projects financed by the Brazilian BNDES ('National Bank for Economic and Social Development') consider in its financial cost a basic rate for long-term projects called TJLP (Long-term Interest Rate), the quarterly interest rate, which is currently equivalent to 6.5% yearly.

For direct operations, the final interest rate is made up of the financial cost and the BNDES rate (including the bank remuneration and the credit risk rate):

Interest Rate = Cost Factor x BNDES Rate Factor -1

Let's consider the example:

Financial cost = 6% p.a.; BNDES rate = 1.3% p.a.

Financial Cost Factor = 1.06; BNDES Rate Factor = 1.013.

Interest rate = 1.06 x 1.013 - 1 = 7.3% p.a..

For indirect operations, the final interest rate is composed of the Financial Cost, the BNDES Rate (including the remuneration of the BNDES and the financial intermediation rate) and the Financial Agent Rate, being made up of the following equation:

Interest Rate = (Cost Factor x 'BNDES' Rate Factor x Agent Rate Factor) - 1

Let us consider the following example:

Financial cost = 6% p.a.; BNDES Rate = 1.3% p.a.; Agent Rate = 3% p.a..

Financial Cost Factor = 1.06; BNDES Rate Factor = 1.015; Agent Rate Factor = 1.03.

In this case, the BNDES interest rate is calculated as:

Interest rate = 1.06 x 1.013 x 1.03 - 1 = 10.6% p.a..

According to the Sectorial Chamber of renewable energies of the Federation of Industries of the State of Ceara (FIEC), the financing rates follow the same financing rules as those of the BNDES and vary according to the company's project rating and payment capacity, location and default factor (the latter factors concerning Northeast Brazil). Additionally, a risk rate is included, which considers the transaction conditions and the and the economic and equity situation of the loan borrower.

At the interest rate adopted for this study, a BNDES interest rate of 6% p.a. and a BNDES rate factor of 1.3% p.a. were considered, and without an intermediary economic agent in the operation, it would result in a wind project financing rate of 7.3% p.a., adopted in this research.

6.3 Total Funding Period

The amortization period is determined according to the capacity of payment of the enterprise, the client or the economic group, respecting the maximum limit of 24 years.

In the case of 'Banco do Nordeste' (BNB), they follow the conditions of the Constitutional Financing Fund of the Northeast - FNE for Infrastructure: Interest rate

IPCA + 1.2765% a.a.

The total funding period is up to 20 years

Both development agents require real guarantees such as: mortgage, pledge, fiduciary property, receivables, etc. defined in the analysis of the operation.

6.4 IRS tax rate in Brazil and Portugal

The average nominal tax rate on distributed profits and dividends to individuals grew in Portugal from 18.7% to 28.9% between 2009 and 2018 and in the Brazilian case, the largest corporative IRS rate, currently is 27%.

6.5 Revenue generated and expected tariffs

The revenues generated by the wind farms considered for the purposes of the study, a total of 8,760 annual hours and a load factor of 50%, in the case of wind farms installed in Brazil, and 30% for the facilities in Portugal.

The consideration of a higher load factor for wind turbines installed in Brazil in relation to the Portuguese congeners was due to the fact that the Brazilian equipment is more recent in installation and incorporates more recent construction technologies. Average tariffs of 31 (USD/MWh) according to EPE [2] were considered for the Brazilian case and an average value of 50 (USD/MWh) for wind energy generated in Portugal. A progressive increase in wind power tariffs expected for the Brazilian energy market should make wind power generation in Brazil even more attractive from an economic point of view.

6.6 Other information regarding Cash Flows

The economic feasibility of stand-alone machine/equipment for wind generation was considered, due to the complexity of the analysis of wind farms. In the absence of specific information regarding the acquisition cost of wind generators, it was taken as a reference a 3 MW wind turbine with an estimated investment of US$ 1.5 million for both generation scenarios in the northeast of Brazil and in continental Portugal. For deployment and infrastructure costs, a ratio of 25% of total costs was adopted, a parameter adopted internationally. Thus, an investment of US$ 2.2 million was adopted for the total implementation costs of a wind generator.

The equipment maintenance cost considered was 1.5% of the equipment acquisition costs per year for the first 10 years of operation and 2.0% from the eleventh year to the twentieth year. The scenario that was taken as reference for the economic analyses in the Brazilian case was the Cash Flow 4 (Appendix 4), which considered a depreciation of 10 years for the wind equipment.

6.7 Cash Flow considered for wind energy generation in Brazil

The standard Cash Flow considered for the elaboration of economic feasibility of wind energy according to Brazilian financing condition for undertakings in Northeast Brazil, was Cash flow 4, shown in Appendix 4, for which we adopted following parameters depicted from Figure 6.1, column 4:

- Investment interest rate (yearly): 7,3% p.a.
- Operation and maintenance costs: 1.5% p.a. for the first 10 years and 2.0% p.a for the last 10 years
- Annual revenue generated in the assessed period: 407,34 USD
- Tariff: 31 [USD/MWh]
- Wind equipment investment: 2,28 [Million USD]
- Total investment civil works inclusive: 3,04 [Million USD]

- Depreciation of equipment: 10 years
- Load factor: 50%
- IRS corporate rate: 27%

For the above Cash Flow, of a 3 MW wind power generator whose investment was estimated at USD 2.28 million and infrastructure expenditures at 760 [USD x 1000] and total investment of 3,04 [USD x 1000], considering the parameters stated in Table 6.1, this investment proved to be economical feasible with following indicators: NPV USD 457,390, IRR 9.22% and Pay back of 15.4 years.

In addition to the elaboration of the investment cash flow, following variables were analyzed: interest rate, load factor, wind turbine investment and wind generation tariff, as shown in Tables 6.2 to 6.5.

Table 6.2: NPV variation due to the variable 'investment rate' – Wind project in Brazil

Investment Rate [%]	4,0	6,0	8,0	10,0	12,0	14,0	16,0
NPV [1000 USD]	1.543,7	832,3	595, 7	-158,5	- 508,4	- 792,2	- 1.025,1
IRR [%]	9,22%	9,22%	9,22%	9,22%	9,22%	9,22%	9,22%

In table 6.2, it can be verified that for interest rates above 9,22 % p.a., the NPV becomes negative and the investment unfeasible; the economic break-even point for this alternative is the internal rate of return itself, 9,22% p.a.

Table 6.3: NPV and IRR variation due to the variable 'load factor' - Wind project in Brazil

Load Factor [%]	20	25	30	35	40	45	50
NPV [1000 USD]	-2,131.1	-1,221.0	- 885.3	-549.6	-213.9	121.7	457.4
IRR [%]	-1.48%	0.94%	2.96%	4.73%	6.34%	7,83%	9.22%

Table 6.3 shows the NPV and IRR variation due to 'load factor' (see Appendix 6); considering the set of variables defined for the standard cash flow; the break-even for this variable is reached for a load factor of 43.18%. Under these conditions, a wind project in Brazil will be economi

Table 6.4: NPV and IRR variation due to the variable 'turbine investment' - Wind project in Brazil

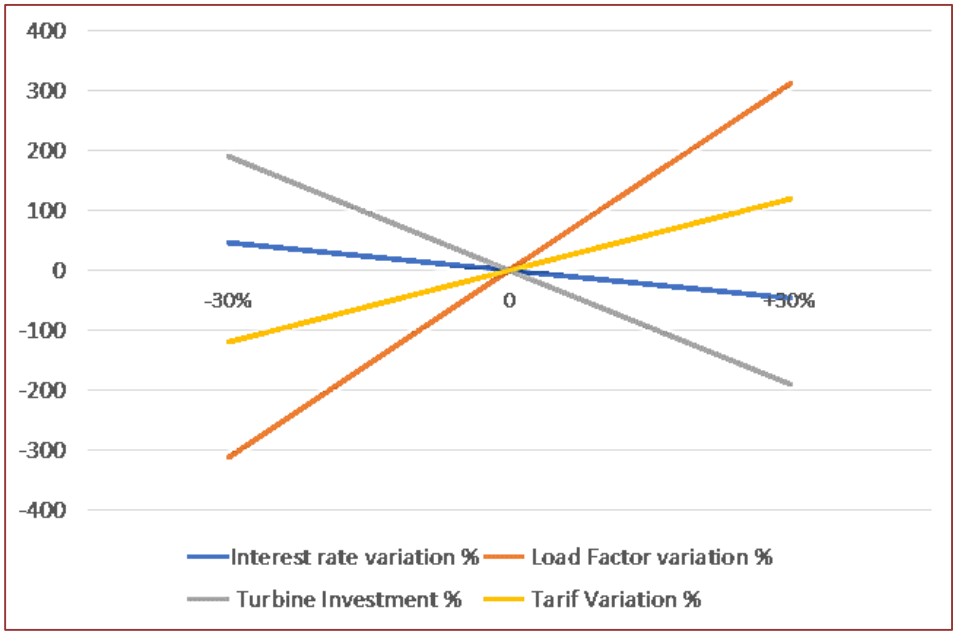
Wind Turbine Investment [USD/MW]	400,00	500,00	600,00	700,00	761,00	800,00
NPV [1000 USD]	1.832,8	1.451,8	1.070,8	689,8	457,4	308,8
IRR [%]	19,78%	15,62%	12,65%	10,38%	9,22%	8,55%

Table 6.5: NPV and IRR variation due to the variable 'tariff' - Wind project in Brazil

Tariff [USD/MW]	25	30	31	40	50	60
NPV [1000 USD]	-192,30	349,10	457,40	1.431,90	2.514,80	3.597,60
IRR [%]	6,40%	8,78%	9,22%	12,91%	16,64%	20,13%

The break-even for the variables 'turbine investment' (Table 6.4) and 'tariff' (Table 6.5) was also calculated and following results were obtained: Wind Turbine Investment equal to 881.11 [USD/kW], see Appendix 7, and 26.73 [USD/MW], see Appendix 8, for the variable 'tariff'.

Figure 6.1: Sensitivity analysis of the variables: Interest Rate, Load Factor, Turbine Investment and Tariff – Cash flow 4 – Wind Investment project in Brazil



Regarding the sensitivity of the variables mentioned above, that is the major or minor impact on the NPV value of the evaluated flows, and as shown in Figure 6.1, the variable with the highest impact is the 'load factor' positively correlated with the NPV followed,

in order, by the variables 'turbine investment' (negatively correlated), 'tariff' (positively correlated) and 'interest rate' with negative correlation.

6.8 Cash Flow considered for wind energy generation in Portugal

Cash Flow 2 (see Appendix 2) represents the economic viability of wind generation according to the technical and tax parameters, considering a 20-year life span and 20-year straight-line depreciation period, as used for wind generation projects in Portugal:

- Investment interest rate (yearly): 8,0% p.a.
- Operation and maintenance costs: 1.5% p.a. for the first 10 years and 2.0% p.a. for the last 10 years
- Annual revenue generated in the assessed period: 525,600 USD
- Tariff: 50 [USD/MWh]
- Wind equipment investment: 2,28 [Million USD]
- Total investment civil works inclusive: 3,04 [Million USD]
- Depreciation of equipment: 20 years
- Load factor: 40%
- IRS corporate rate: 28,9%

According to these parameters, wind generation in Portugal is economically viable, and for this Cash Flow the Net Present Value calculated yearly was USD 704,543.89, the Internal Rate of Return (IRR) 11.01%, exceeding the adopted project finance cost of 8% p.a. and the investment Payback occurs in 13.3 years.

Tables 6.6 to 6.9 show the variation of the variables ‘investment rate’, ‘load factor’, ‘turbine investment’ and ‘tariff’. The break-even for each of this variable is, according to above Cash Flow: investment rate, 11,01% (see Appendix 10), load factor, 32,32% (see Appendix 11), turbine investment, 941,85 [USD/MW], see Appendix 12 and Tariff, 40,39 [USD/MW], Appendix 13.

Table 6.6: NPV variation due to the variable 'investment rate' – Wind project in Portugal

Investment Rate	4%	6%	8%	10%	12%	14%	16%
NPV [1000 USD]	2.132,01	1.330,00	704,54	209,98	-186,28	-507,84	-771,92

Table 6.7: NPV and IRR variation due to load factor – Wind project in Portugal

Load Factor [%]	20	25	30	35	40	45	50
NPV x 1000 USD	-1.129,98	-671,35	-212,72	245,91	704,54	1163,17	1621,8
IRR [%]	2,41%	4,84%	7,04%	9,08%	11,01%	12,85%	14,63

Table 6.8: NPV and IRR variation due to the variable 'turbine investment' - Wind project in Portugal

Turbine Investment [USD/MW]	600	700	761	800	900	1000
NPV [1000 USD]	1.331,72	942,17	704,54	552,61	163,06	-226,49
IRR [%]	14,89%	12,30%	11,01%	10,27%	8,61%	7,72%

Table 6.9: NPV and IRR variation due to the variable 'tariff' - Wind project in Portugal

Tariff [USD/MW]	25	30	40	50	60	70
NPV [1000 USD]	-1.129,98	-763,07	-29,26	704,54	1.438,35	2.172,16
IRR [%]	2,41%	4,37%	7,87%	11,01%	13,93%	16,71%

The break-even of the variables 'interest rate', 'load factor', 'turbine investment' and 'tariff' are shown in Table 6.10. For the variables 'interest rate' and 'tariff', the break-even for wind projects in Brazil are below the corresponding break-even in similar projects in Portugal. In the case of the load factor and turbine investment variables, the opposite is true.

Table 6.10: Break-even of the variables 'interest rate', 'load Factor', 'turbine investment' and 'tariff' for wind projects in Brazil and Portugal

	Interest rate [%]	Load Factor [%]	Turbine Investment [USD/kW]	Tariff [USD/MW]
Brazil	9.22	43.18	881.11	26.73]
Portugal	11,01	32.32	941.85	40.39

cally viable if the load factor is greater than 43.18%.

CHAPTER

07 CONCLUSION

This research aimed to analyze the economic viability of wind generation in Northeast Brazil, as well as to define the variables that currently most strongly impact the viability of operating equipment and wind farms, identifying its key economic impact, such as technologies, equipment size and load factor among others.

In this context, wind conditions, their intensity, direction, duration, and probability of occurrence was taken from surveys conducted by the Ceara State Secretariat of Infrastructure (SEINFRA) [25] published in the document ''Wind and Solar Atlas of Ceara State' provided for this research by the Ceara Federal University.

The research also aimed to analyze the viability of wind generation in Portugal as a comparison to similar generation in Brazil. Information for this research was also obtained from technical reports published by ABEEOLICA, EPE (Energy Planning Company) of the Brazilian Ministry of Mines and Energy, as well as information regarding wind project financing conditions, provided by the Federation of Industries of the State of Ceara.

Deterministic models were used in the analysis of investment projects, which included the elaboration of Cash Flows and the adoption of indicators such as Net Present Value, Internal Rate of Return and Pay-back, complemented with a sensitivity analysis of the main variables impacting the economic viability of wind investments in Brazil and Portugal.

The cash flow analysis allowed the calculation of the break-even for the different variables analyzed, equipment load factor, wind turbine investment and effective hours available for wind generation, among others.

Although for the situation analyzed, wind generation projects in the Northeast of Brazil are economically viable, the profitability of these projects for the assumptions of the calculation assumed is still low, considering they generate a 15 years Pay-back and a return rate of 9.22% as opposed to an assumed financing cost of 7,3% p.a. (BNDES interest rates for the financing of larger wind generation projects) and also in view of the risks involved in the projects; in the Brazilian case, tariff fluctuations (due to the auctions practiced), risk in the wind equipment prices due to monetary exchange variations, and even the existence of non-controllable variables such as wind intensity and duration.

For the standard flows considered for generation in Brazil and Portugal, shown in columns 2 and 4 of Table 6.1., yields expressed in terms of internal rate of return are respectively of 9, 22% for Brazil and 11.01% for Portugal.

Despite this difference in yields of 1.79% p.a, there is still a relative balance in these returns as it was considered an average load factor of 40% for new projects in Portugal. If we consider a more realistic 35% load factor parameter for equipment and parks already operating in Portugal, the profitability is reduced to 9.01%, and is therefore very close to the 9.22% assumed for the situation in Northeast Brazil.

The sensitivity of the variables 'interest rate', 'load factor', 'turbine investment' and 'tariff', the variables with the greatest impact on the Cash Flows analyzed, were calculated as shown in Tables 6.2 to 6.5 for Brazilian wind projects and Tables 6.6 to 6.9 for wind projects in Portugal. Among these, in the Brazilian case, the variable with the highest impact was the 'load factor' positively correlated with the NPV followed, in order, by the variables 'turbine investment' (negatively correlated), 'tariff' (positively correlated) and 'interest rate' with negative correlation.

We simulated the impact of depreciation on wind projects for Northeast Brazil with the following result: depreciation extended to the 20-year analysis horizon for standard Cash Flow results into an NPV of USD 457,395.63 and IRR of 9.22%; by applying a 5-year accelerated average depreciation for assets, NPV increases to USD 848,030.3 and IRR to 10.72% p.a.

The research showed that profitability of wind generation projects can be improved, making these investments more attractive, through government action by a) reducing taxes on wind equipment and IRS rates and b) reducing the depreciation period of related equipment/assets and c) offering lower interest rates to finance wind generation projects.

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Appendix 1

Cash Flow 1 – According to Brazilian technical parameters and legislation, 20-year life span, 20-year depreciation

Values [US$]											
Year	0	1	2	3	4	5	6	7	8	9	10
Revenues		407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00
Operation & Maintenance Costs		45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	60.880,00
Initial Investment (US$)	-3.044.000,00										
Cash Flow (CF) without depreciation	-3.044.000,00	453.000,00	453.000,00	453.000,00	453.000,00	453.000,00	453.000,00	453.000,00	453.000,00	453.000,00	468.220,00
Depreciation		152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00
CF - Depreciation	-3.044.000,00	300.800,00	300.800,00	300.800,00	300.800,00	300.800,00	300.800,00	300.800,00	300.800,00	300.800,00	316.020,00
IRS Values	-3.044.000,00	81.216,00	81.216,00	81.216,00	81.216,00	81.216,00	81.216,00	81.216,00	81.216,00	81.216,00	85.325,40
CF - Depreciation - IR	-3.044.000,00	219.584,00	219.584,00	219.584,00	219.584,00	219.584,00	219.584,00	219.584,00	219.584,00	219.584,00	230.694,60
CF - Depreciation - IR + Depreciation	-3.044.000,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	382.894,60
CF after Depreciation and IR	-3.044.000,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	371.784,00	382.894,60
DCF (discounted Cash Flow)	-3.044.000,00	346.490,21	322.917,25	300.948,05	280.473,48	261.391,88	243.608,46	227.034,91	211.588,92	197.193,77	189.270,10
ACF (Added Cash Flow)	-3.044.000,00	-2.697.509,79	-2.374.592,53	-2.073.644,48	-1.793.171,00	-1.531.779,12	-1.288.170,67	-1.061.135,76	- 849.546,84	- 652.353,06	- 463.082,96

Values [US$]										
Year	11	12	13	14	15	16	17	18	19	20
Revenues	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00
Operation & Maintenance Costs	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00
Initial Investment (US$)										
Cash Flow (CF) without depreciation	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00	468.220,00
Depreciation	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00
CF - Depreciation	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00	316.020,00
IRS Values	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40	85.325,40
CF - Depreciation - IR	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60	230.694,60
CF - Depreciation - IR + Depreciation	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60
CF after Depreciation and IR	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60	382.894,60
DCF (discounted Cash Flow)	176.393,39	164.392,72	153.208,50	142.785,18	133.071,00	124.017,70	115.580,34	107.717,00	100.385,63	93.555,83
ACF (Added Cash Flow)	- 286.689,57	- 122.296,85	30.911,65	173.696,83	306.767,82	430.785,53	546.365,87	654.082,87	754.471,50	848.030,33
									NPV	**848.030,33**
									IRR [%]	**10,72%**

Appendix 2

Cash Flow 2 – According to Portuguese parameters and legislation, 20-year life span and 20-year straight-line depreciation period

Values [US$]											
Year	0	1	2	3	4	5	6	7	8	9	10
Revenues		525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00
Operation & Maintenance Costs		45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00
Initial Investment (US$)	-3.044.000,00										
Cash Flow (CF) without depreciation	-3.044.000,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00	479.940,00
Depreciation		152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00
CF - Depreciation	-3.044.000,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00	327.740,00
IRS Values	-3.044.000,00	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86	94.716,86
CF - Depreciation - IR	-3.044.000,00	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14	233.023,14
CF - Depreciation - IR + Depreciation	-3.044.000,00	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14
CF after Depreciation and IR	-3.044.000,00	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14	385.223,14
DCF (discounted Cash Flow)	-3.044.000,00	356.686,09	330.266,75	305.802,55	283.150,51	262.176,40	242.755,92	224.774,00	208.124,08	192.707,48	178.432,85
ACF (Added Cash Flow)	-3.044.000,00	-2.687.311,91	-2.357.045,16	-2.051.242,61	-1.768.092,10	-1.505.915,70	-1.263.159,78	-1.038.385,78	-830.261,70	-637.554,22	-459.121,37

Values [US$]										
Year	11	12	13	14	15	16	17	18	19	20
Revenues	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00	525.600,00
Operation & Maintenance Costs	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00
Initial Investment (US$)										
Cash Flow (CF) without depreciation	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00	464.720,00
Depreciation	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00	152.200,00
CF - Depreciation	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00	312.520,00
IRS Values	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28	90.318,28
CF - Depreciation - IR	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72	222.201,72
CF - Depreciation - IR + Depreciation	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72
CF after Depreciation and IR	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72	374.401,72
DCF (discounted Cash Flow)	160.574,46	148.680,07	137.666,74	127.469,20	118.027,04	109.284,29	101.189,16	93.693,67	86.753,40	80.327,22
ACF (Added Cash Flow)	-298.546,89	-149.866,82	-12.200,08	115.269,12	233.296,15	342.580,45	443.769,61	537.463,27	624.216,67	704.543,89
									NPV	704.543,89
									TIR	11,01%

Appendix 3

Cash Flow 3 – According to Brazilian technical parameters and legislation, 20-year life span, 5-year depreciation

Values [US$]											
Year	0	1	2	3	4	5	6	7	8	9	10
Revenues		407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00
Operation & Maintenance Costs		45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00
Initial Investment (US$)	-3.044.000,00										
Cash Flow (CF) without depreciation	-3.044.000,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00
Depreciation		-608.800,00	-608.800,00	-608.800,00	-608.800,00	-608.800,00					
CF - Depreciation	-3.044.000,00	-247.120,00	-247.120,00	-247.120,00	-247.120,00	-247.120,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00
IRS Values	-3.044.000,00	0	0	0	0	0	97.653,60	97.653,60	97.653,60	97.653,60	97.653,60
CF - Depreciation - IR	-3.044.000,00	-247.120,00	-247.120,00	-247.120,00	-247.120,00	-247.120,00	264.026,40	264.026,40	264.026,40	264.026,40	264.026,40
CF - Depreciation - IR + Depreciation	-3.044.000,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00
CF after Depreciation and IR	-3.044.000,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00
DCF (discounted Cash Flow)	-3.044.000,00	337.073,63	314.141,31	292.769,16	272.851,04	254.285,01	236.987,89	220.864,77	205.838,55	191.834,62	178.783,43
ACF (Added Cash Flow)	-3.044.000,00	-2.706.926,37	-2.392.785,06	-2.100.015,90	-1.827.164,87	-1.572.879,86	-1.335.888,96	-1.115.024,20	-909.185,65	-717.351,02	-538.567,59

Values [US$]											
Year	11	12	13	14	15	16	17	18	19	20	
Revenues	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	
Operation & Maintenance Costs	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	
Initial Investment (US$)											
Cash Flow (CF) without depreciation	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
Depreciation											
CF - Depreciation	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
IRS Values	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	
CF - Depreciation - IR	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	
CF - Depreciation - IR + Depreciation	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
CF after Depreciation and IR	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
DCF (discounted Cash Flow)	159.608,55	148.749,52	138.629,84	129.198,36	120.403,53	112.216,71	104.582,21	97.467,11	90.836,08	84.656,18	
ACF (Added Cash Flow)	-378.959,03	-230.209,22	-91.579,38	37.618,98	158.027,51	270.244,23	374.826,44	472.293,55	563.129,63	647.785,81	
										647.785,81	NPV
										9,996%	TIR #1

Appendix 4

Cash Flow 4 – According to Brazilian parameters and legislation, 20-year life span and a 10-year straight-line depreciation period.

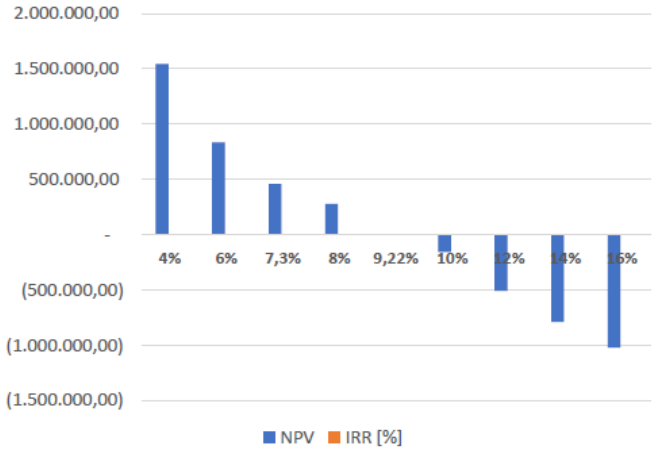
Values [US$]											
Year	0	1	2	3	4	5	6	7	8	9	10
Revenues		407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00
Operation & Maintenance Costs		45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00	45.660,00
Initial Investment (US$)	-3.044.000,00										
Cash Flow (CF) without depreciation	-3.044.000,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00	361.680,00
Depreciation		- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00	- 304.400,00
CF - Depreciation	-3.044.000,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00	57.280,00
IRS Values	-3.044.000,00	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60	15.465,60
CF - Depreciation - IR	-3.044.000,00	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40	41.814,40
CF - Depreciation - IR + Depreciation	-3.044.000,00	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40
CF after Depreciation and IR	-3.044.000,00	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40	346.214,40
DCF (discounted Cash Flow)	-3.044.000,00	322.660,21	300.705,49	280.230,22	261.153,50	243.414,34	226.854,19	211.420,49	197.036,50	183.631,69	171.138,57
ACF (Added Cash Flow)	-3.044.000,00	-2.721.339,79	-2.420.631,31	- 2.140.381,09	-1.879.197,29	-1.635.782,75	- 1.408.928,56	- 1.197.508,07	- 1.000.471,27	- 816.839,58	- 645.701,01

Values [US$]												
Year	10	11	12	13	14	15	16	17	18	19	20	
Revenues	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	407.340,00	
Operation & Maintenance Costs	45.660,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	60.880,00	
Initial Investment (US$)												
Cash Flow (CF) without depreciation	361.680,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
Depreciation	- 304.400,00											
CF - Depreciation	57.280,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
IRS Values	15.465,60	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	93.544,20	
CF - Depreciation - IR	41.814,40	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	252.915,80	
CF - Depreciation - IR + Depreciation	346.214,40	252.915,80	252.915,80	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
CF after Depreciation and IR	346.214,40	252.915,80	252.915,80	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	346.460,00	
DCF (discounted Cash Flow)	171.138,57	116.514,24	106.567,37	136.629,84	129.195,36	120.408,53	112.216,71	104.582,21	97.467,11	90.836,05	84.656,15	
ACF (Added Cash Flow)	- 645.701,01	- 529.186,76	-420.599,40	- 281.969,56	- 152.771,20	- 32.362,67	79.854,05	184.436,26	281.903,37	372.739,45	457.395,63	
											457.395,63	NPV
											9,221%	TIR #1

Appendix 5

Break-even of the Variable 'Interest Rate' – Investment project in Brazil

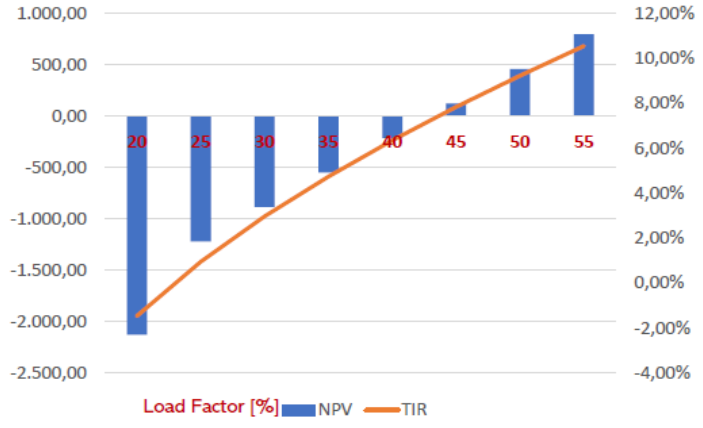
(Break-even of 'Interest Rate = 9,22%)



Appendix 6

Break-even for the Variable 'Load Factor' - Investment project in Brazil

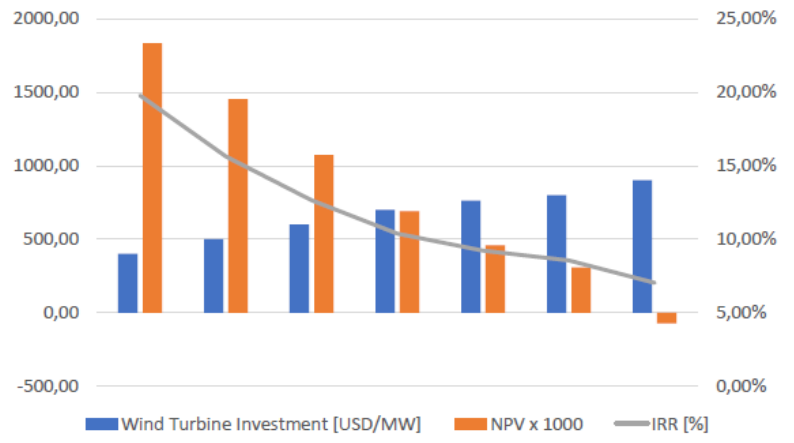
(Break-even of 'Load Factor' = 43,18%)



Appendix 7

Break-even for the Variable 'Wind Turbine Investment' - Investment project in Brazil

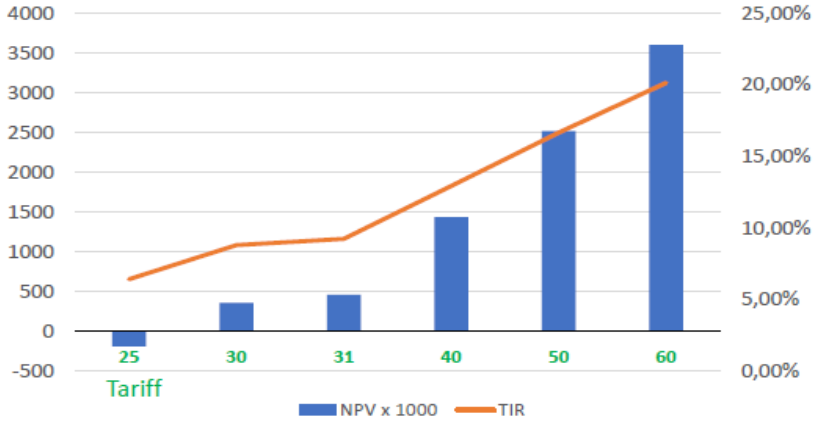
(Break-even of 'Turbine Investment' = 881,11 [USD/kW]



Appendix 8

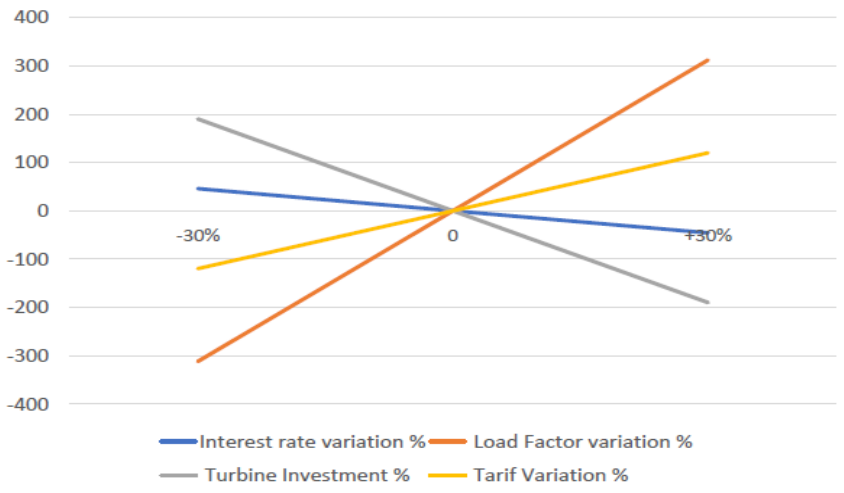
Break-even for the Variable 'Tariff' - Investment project in Brazil

(Break-even of 'Tariff' = 26,73 [USD/MW]



Appendix 9

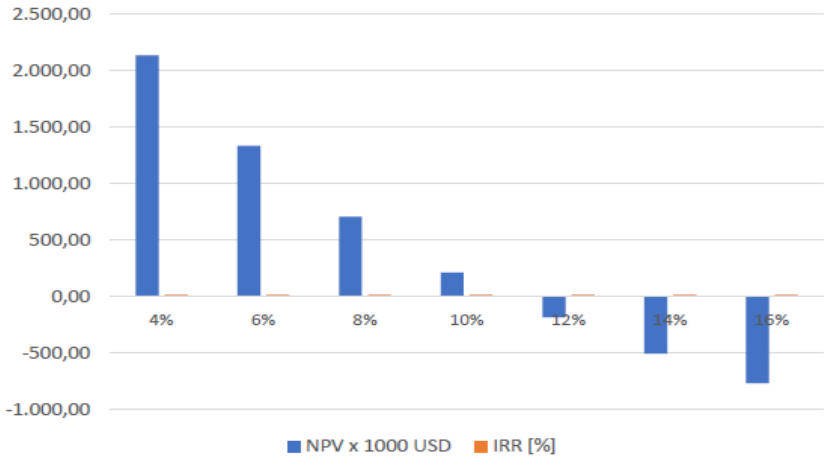
Sensitivity Analysis, measured in NPV variation [%], of the main Variables of a Wind Generating Project in Northwestern Brazil



Appendix 10

Break-even for the Variable 'Interest Rate' – Investment project in Portugal

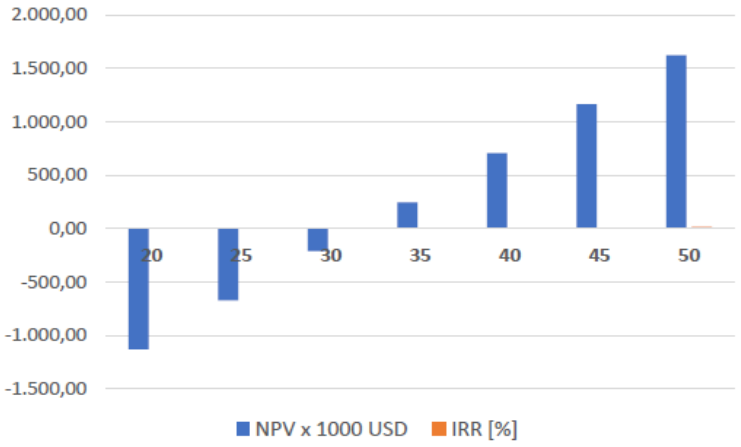
(Break-even of the Interest Rate = 11,01%)



Appendix 11

Break-even for the Variable 'Load Factor' – Investment project in Portugal

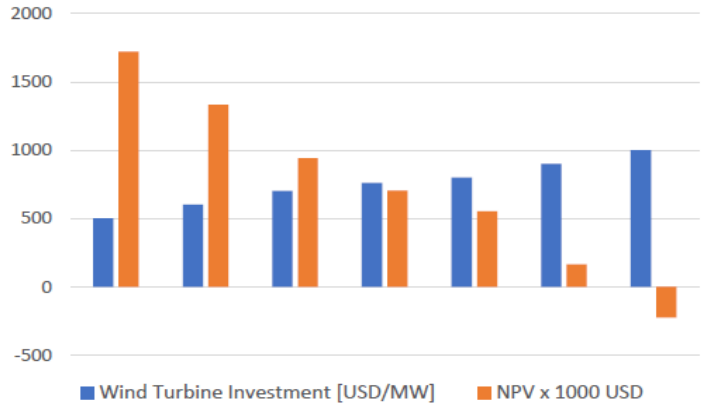
(Break-even of 'Load Factor' = 32,32%)



Appendix 12

Break-even for the Variable 'Wind Turbine Investment' – Investment project in Portugal

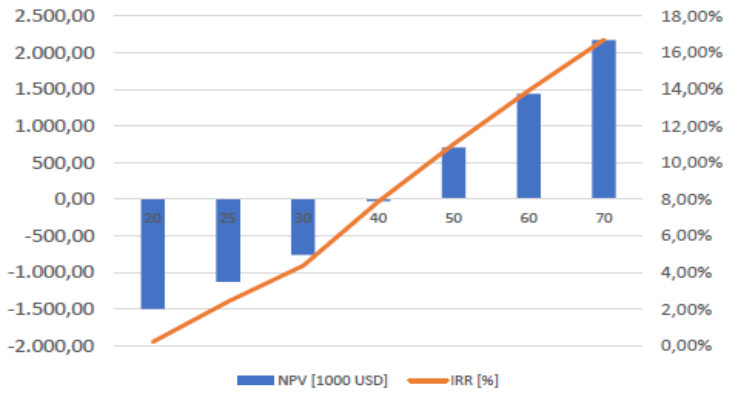
(Break-even of ' Turbine Investment' = 941,85 [USD/kW]



Appendix 13

Break-even for the Variable 'Tariff' – Investment project in Portugal

(Break-even of 'Tariff' = 40.39 [USD/MW]



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